RIODICAL - Australia. C.S.I.R.O
.247
LIBRARY
FISH & WILDLIFE SERVICE
PACIFIC OCEANIC FISHERY
INVESTIGATIONS
Bulletin
JOHN LAURENCE KASK
JUL 28 1950
#247

MARINE CRAYFISHES OF WESTERN AUSTRALIA

BULLETIN No. 247

COMMONWEALTH SCIENTIFIC AND INDUSTRIAL RESEARCH ORGANIZATION, AUSTRALIA

MELBOURNE 1949

REGISTERED IN AUSTRALIA FOR TRANSMISSION BY POST AS A PERIODICAL

The Marine Crayfishes (Spiny Lobsters), Family Palinuridae, of Western Australia

with particular reference to the fishery on the Western Australian Crayfish (*Panulirus longipes*)

By Keith Sheard

BULLETIN No. 247

(Division of Fisheries - Report No. 18)

Commonwealth Scientific and Industrial Research Organization, Australia

(formerly Council for Scientific and Industrial Research)

Melbourne 1949

CONTENTS

	Page
Summary	5
I. General	7
(*a*) Introduction	7
(*b*) Marine crayfishes of Western Australia, species and distribution	7
(i) The genus *Jasus*	8
(ii) The genus *Panulirus*	9
II. The Commercial Species *Panulirus longipes* (M.-E.)	10
(*a*) Distribution	10
(*b*) Relationships	10
(*c*) Life History and Dispersal Phases	10
(i) Larval stages	10
(ii) Dispersion of larvae	11
(iii) Juvenile and adult stages	12
(iv) White crayfish	12
(v) Moulting, mating, and egg-laying	13
(vi) Migration in the crayfish phase	14
(*d*) Geological and Geographic Environment	14
(i) General	14
(ii) Houtman's Abrolhos	15
(*e*) Population Controls	15
(i) Unfavourable current conditions	15
(ii) Predator pressure	16
(iii) Environmental changes and faulty adaptation	16
(iv) Interspecific competition	17
(v) Intraspecific competition	17
(vi) Unrestricted and badly managed fisheries	17
(*f*) Natural Sanctuaries	18
(*g*) Length and Weight Frequencies and Correlations	18
(*h*) Tagging and Marking Tests	20
(i) Tagging	20
(ii) Marking	21
(*i*) Hatchery Prospects	22

Contents—*continued*

Page

III. The Commercial Fishery in Western Australia 22
(*a*) Fishery Areas 22
(*b*) Fishery Practice 24
(i) Catching methods 24
(ii) Storage and transport 25
(iii) Fishery conditions, Abrolhos Group 25
(*c*) Recruitment of Stocks, Abrolhos Group 26
(*d*) Regulation of the Fishery 27
(*e*) Statistics 28
(*f*) Conservation 31
(i) Lodgment of larvae 31
(ii) The optimum catch 31

IV. Investigations in Western Australian Waters 36
(*a*) Exploration and Commercial Testing 36
(i) *Jasus lalandii* 36
(ii) *Panulirus longipes* 36
(iii) The " coral " crayfishes 36
(*b*) Technical Investigations 36
(i) *Jasus lalandii* 36
(ii) *Panulirus longipes* 36
(*c*) Biological Investigations 38
(i) *Jasus lalandii* 38
(ii) *Panulirus longipes* 39

V. A Working Key to the Genus *Panulirus* 41

VI. Acknowledgments 43

VII. References 44

SUMMARY

The two genera of the family Palinuridae which occur in the waters of the coastal shelf of Western Australia, are the genus *Jasus*, with the species *Jasus lalandii* occurring between the Recherche Archipelago in the east and Cape Naturaliste in the west ; and the genus *Panulirus*, with one species, *Panulirus longipes*, dominant between Cape Leeuwin in the south and North-West Cape in the north, and four species, *P. ornatus*, *P. versicolor*, *P. penicillatus*, and *P. burgeri*, extending northwards from the North-West Cape area. The commercial fishery exploits the species *P. longipes* in the waters west and north of Fremantle, off Dongara and Geraldton, and at Houtman's Abrolhos. The major part of this bulletin outlines the general biology of the species and describes the environment and fishing methods.

There are indications that the annual recruitment (the number of stock yearly entering the fishery areas) is basically through the lodgment of juveniles which may be hatched from eggs carried by females from distant areas. Large areas of coastal waters are inaccessible to fishermen at present. If this condition continues there is little danger of permanent depletion of the present fishing grounds, although they may be temporarily overfished.

The age groups fished are the late second and the third and early fourth years from the moult into the true crayfish form.

Punch marks of various designs placed on the telson are of value in determining the extent and direction of adult movement and in obtaining population estimates through release and recapture tests in defined areas.

Methods of regulating the fishery are examined. It is suggested that in heavily fished areas it is unwise to permit the development of fishery practices which interfere with the departmental inspection of the crayfish before their processing for market.

Particular attention has been paid to the fishery at Houtman's Abrolhos. The area over which the fishermen can operate efficiently is limited. Careful management is required to avoid over-fishing, and to ensure that the best weight of crayfish flesh may be taken during the season.

An outline of investigations in Western Australian waters is given, together with a key to the genus *Panulirus*, and a general list of references to the subject.

The Marine Crayfishes (Spiny Lobsters), Family Palinuridae, of Western Australia

With particular reference to the fishery on the Western Australian Crayfish (*Panulirus longipes*)*

By Keith Sheard

I. GENERAL

(*a*) *Introduction*

During the rapid expansion of the fishery on the Western Australian Crayfish (*Panulirus longipes*) in 1945 representations were made by the Western Australian Chief Inspector of Fisheries, Mr. A. J. Fraser, to Dr. Harold Thompson, Chief of the Division of Fisheries, C.S.I.R., for a survey of the factors relating to the fishery in that State. The writer was assigned to this work in 1946. Little has been published on Palinurid crayfish biology or fishery practice, while no organised data existed on the Western Australian crayfishery. Accordingly it was necessary to conduct a preliminary examination over the whole field. The following general outline is introductory to more detailed studies of the species and of the fishery particularly at the Houtman's Abrolhos. This detailed work has been in progress during 1947 and 1948, and will be reported on elsewhere.

(*b*) *Marine Crayfishes of Western Australia, Species and Distribution*

Species identified so far in Western Australian waters and some of the corresponding Australian vernacular names are :

Jasus lalandii (Milne-Edwards)—Southern spiny lobster, southern marine crayfish, Tasmanian crayfish. In Western Australia, lobster, red lobster.

Panulirus longipes (Milne-Edwards)—Abrolhos crayfish, Dongara crayfish, Rottnest crayfish, Western Australian crayfish, red crayfish, rock lobster.

" White Crayfish " applies to recently moulted, newly mature specimens from shallow water in fishing areas off Rottnest Island. At Houtman's Abrolhos the corresponding term is " pink," or " coral " crayfish.

Panulirus ornatus (Fabricius)—Painted crayfish, coral crayfish, Queensland crayfish, north-west crayfish.

Panulirus penicillatus (Olivier)—Coral crayfish, north-west crayfish.

* Typescript received August 5, 1948

Panulirus versicolor (Latreille)—Coral crayfish, north-west crayfish.

Panulirus burgeri (de Haan).—Green crayfish, Onslow crayfish.

The New South Wales crayfish, *Jasus verreauxi* (M.-E.), has not been found in Western Australian waters. The corresponding ecological niche appears to be filled by *Panulirus longipes*.

True marine lobsters of the family Homaridae are not known from Australian waters.

(i) The genus *Jasus*—The genus *Jasus* is confined to the cooler neritic waters of the Southern Hemisphere and includes two species, *J. lalandii* and *J. verreauxi*. *J. lalandii*, the principal commercial species of the genus, has a circumpolar distribution range from 32° to 45°S. latitude. It is recorded from St. Paul, Tristan da Cunha, and, doubtfully, from Juan Fernandez, and is fished commercially in South Africa, Australia, and New Zealand. In Australian waters the main areas of distribution are South Australian, Victorian, and Tasmanian onshore and offshore reefs. The species also occurs in the southern waters of New South Wales and Western Australia, and occasionally specimens have been obtained as far north as Sydney on the east coast, and Dongara on the west.

Although the chief commercial fishery is in Tasmanian waters, considerable numbers are taken in the south-east of South Australia in depths down to forty-five fathoms, along the western end of the south coast of Kangaroo Island, and off Althorpe Island and Cape Spencer. The species does not penetrate into the waters of Spencer or St. Vincent Gulfs. On the west coast of South Australia the species is certainly present northwards at least to Fowler's Bay, but no commercial fishery exists, excepting small occasional catches off Streaky Bay. A table giving the comparative yields from the States of Victoria and Tasmania is given in Section III. 5 (Statistics).

In a recent publication, the first of its kind on Australian Marine Crayfishes, Hickman (1946) has summarised notes on some aspects of the biology of *J. lalandii* in Tasmanian waters, based on the examination of 1,058 specimens taken over a period of five years mainly at Wedge Bay, Tasman Peninsula, Tasmania. This work is being continued in association with the Division of Fisheries, C.S.I.R.

In Western Australian waters the species occurs southwards from Cape Naturaliste to Cape Leeuwin, thence eastwards to at least Cape Arid and Recherche Archipelago. From Cape Naturaliste to Cape Leeuwin it occurs together with *Panulirus longipes*, and specimens are occasionally found along the western coast as far north as Rottnest Island and Dongara. In February 1947, about twenty specimens were noted in local fish shops but none of these was caught north of Rottnest Island.

While there is some evidence from amateur fishing practice that the occurrence of *J. lalandii* is seasonal on the onshore reefs (particularly on the granites of the Cape Naturaliste-Cape Leeuwin area), the point is difficult to determine as the winter seas are heavy and conditions are not favourable for detailed tests throughout the year. A very small coastal ledge fishery operating from October to May exists at Yallingup, south of Cape Naturaliste, but with the exception of this and some isolated amateur fishing, particularly in the Hamelin Bay-Margaret River area, there is no exploitation. Some very limited spot tests indicate the presence of crayfish to a depth of sixty fathoms over the general range but

their presence in commercial quantities remains to be proved. From local accounts, weather and havens in this region resemble to some extent that of the Kingston-Port Macdonell area in South Australia, where fishing operations can only be carried out for about seventy or eighty days during the year with the present type of boat and gear.

(ii) The genus *Panulirus*—This genus, which occurs in tropical and sub-tropical neritic waters of both hemispheres, contains many species. A working key is given in Section V. Six species have been recorded as occurring in east Australian tropical waters but the five commented upon below appear to be those which are found in significant numbers in Western Australian waters.

The world distribution of these species is as follows :

Panulirus ornatus (Fabricius).—Zanzibar, Mauritius, Ceylon, Bengal, Singapore, Macassar, Amboina, Philippine Is., East Indies generally, New Guinea, and Samoa.

Panulirus penicillatus (Olivier).—From the Gulf of Akaba to Korea, Hawaiian and Gambier Is., New Hebrides, New Guinea, and East Indies generally.

Panulirus versicolor (Latreille).—Zanzibar, Seychelles, Mauritius, Christmas Island, New Guinea, New Britain, East Indies generally, and Japan.

Panulirus longipes (Milne-Edwards).—Indian Ocean reef areas.

Panulirus burgeri (de Haan).—Indian Ocean reef areas.

In Australia these species have been recorded from many coral reef areas north of the Tropic of Capricorn, and, with the exception of P. *longipes*, occasionally southwards along the east coast of Australia, but little is known of their habits, biology, or population density. During recent field work in Western Australia the first three species, together with *Panulirus longipes*, were obtained along North-West Cape Peninsula from Maud's Landing to North-West Cape. They are apparently more tolerant of silty and muddy bottoms than is P. *longipes*, and move inshore along the channels of the dead coral reefs at night for feeding purposes. North of North-West Cape their distribution is not well known. One or other of the species occurs north of this point under the vernacular names of the " North-West " or " Coral " crayfishes, but nothing is known of the distribution of the individual species. A specimen photographed at Onslow by Mr. S. Fowler was P. *versicolor* as were specimens obtained by the Commonwealth lighthouse tender, *Cape Otway*, off Bedout Island, Broome, in August 1948. P. *burgeri* appears to be common on the reefs of islands in the Onslow area. Occasionally specimens of P. *ornatus* have been taken as far south as Dirk Hartog Island and Bernier Island. The flesh of P. *ornatus* is somewhat flavourless, watery, and tough, but that of the other three species is at least equal to that of P. *longipes*. The canned and the cooked products are firm and of a good flavour.

II. THE COMMERCIAL SPECIES *PANULIRUS LONGIPES* (M.-E.)

(*a*) *Distribution*

This species appears to be confined to the Indian Ocean, being recorded from Zanzibar, Mauritius, and Western Australia. It has not been recorded from any other Australian waters.

The distribution of this species in Western Australia has been traced from Cape Leeuwin in the south to North-West Cape in the north, a range of about 12 degrees of latitude. There is no record of the occurrence of *P. longipes* on the mainland reefs north of that point, but it has been reported from Muiron Island by men familiar with the species. From Cape Naturaliste to the commencement of the Little Barrier Reef at about Lat. 23°S., south of North-West Cape Peninsula, it is the only species present in any numbers.

(*b*) *Relationships*

The species is very closely related to *Panulirus japonicus* (von Siebold), the chief taxonomic difference being the possession by *P. longipes* of true spines posterior to the main spines on the dorsal surface of the antennal segment, which in this genus forms a fairly long plate in front of the carapace. These spines are present at all moult stages, growing larger and more definite with age. They form two rows of three, with sometimes four, small spines immediately behind the two principal spines. Near the frontal margin of the antennal segment is a row of small tubercles. In such specimens of P. *japonicus* as the author has examined (from New Guinea waters), and in published descriptions, the posterior area of the antennal segment is either bare or possesses some scattered spinules forming no set pattern. The frontal margin of the plate possesses small spines in both species.

Sexual dimorphism in the legs is apparent only in large males with carapace over 4½ ins. in length, unlike the Japanese findings with regard to P. *japonicus* (Kubo 1938). The legs of both sexes in P. *longipes* are longer relative to body or to carapace length than are those of *P. japonicus*. The recorded distribution of P. *japonicus* is from the warm waters of the Pacific Ocean, and of *P. longipes* from the warm waters of the Indian Ocean, with an extension to the Amboina region, if *P. femoristriga* (von Marten) is regarded as a synonym of *P. longipes* (M.-E.). Since, in spite of the revisions of Gruvel (1911), and de Man (1916), the species of the family *Palinuridae* are not well known and the species limits are ill-defined, it is better to retain the name *Panulirus longipes* (M.-E.) for the Western Australian commercial species pending a complete examination of P. *japonicus* and allied species.

Although Spence Bate's description is inadequate, there appears to be a close relationship between *P. longipes* and *P. guttatus* var. of Spence Bate (1888, p. 57, Pl. XA) from St. Paul's Rocks in the South Atlantic.

(*c*) *Life History and Dispersal Phases*

(i) *Larval stages.*—In common with the other species of the family Palinuridae the eggs, which are carried as " berry " on the swimmerets, hatch at an earlier stage of development than in the allied family Homaridae, to which the clawed lobsters belong. The

first stage is a naupliosoma quickly followed by the first of a number of phyllosoma stages, flat, leaf-like forms with the legs modified for swimming. At the conclusion of the phyllosoma stages the larva moults into a puerilla, a form which resembles the crayfish but possesses no lime in its skeleton. This finally moults into a small, immature crayfish, deposits lime in its skeleton, and becomes a bottom-living organism.

During these stages the larva passes through some reversals in its reaction to light intensity. The naupliosoma avoids light, creeping into rock cracks etc. for protection, but the early phyllosoma are strongly attracted by bright light and so concentrate in the surface water layers. The mid-phyllosomas act much in the same way as do typical plankton animals, tending to react positively to light of a certain low intensity, and so sinking to deeper water layers in the daytime and rising to higher levels at night. In perhaps the last phyllosoma, certainly in the puerilla stage, the larva seeks the light again and floats in the surface-water layers. In the first lime-bearing stage, and from then on through its adult life, it avoids light of more than slight intensity.

In different species the duration of larval life ranges from about three to perhaps six or seven months and covers the main dispersal phase of the species concerned. In *P. longipes* the duration of larval life is not known, but from tow-netting evidence a period of about five months is indicated. The last phyllosoma and puerilla stages measure between five and seven centimetres in length.

During the phyllosoma stages the larvae are at the mercy of current movements, the relations being as follows : (1) Early phyllosoma : surface currents and wind-drifts ; (2) Mid and late phyllosoma : mid-water to surface currents ; (3) Late phyllosoma and puerilla : surface currents and wind-drifts.

The duration of the puerilla stage is not known but it may be about ten to fourteen days. Puerilla of unusually large sizes have been taken, indicating that the duration of this stage may be prolonged, producing forms comparable to the " Glaucothoe " stage of the Paguridae and the "Grimothoe " stage of Munida, these stages being " giant " larvae resulting from lengthening of the normal larval period.

(ii) *Dispersion of larvae.*—Over the southern range of distribution of this species in Western Australia, hatching of the eggs has been observed from December until February with some isolated cases in November and March. Last stage phyllosoma, the puerilla, and the first juvenile crayfish stage have been seen from June to October.

The result of monthly drift bottle releases (still in progress) made by various agencies under the direction of Dr. D. L. Serventy, tend to suggest : " A southward flow in winter along the west coast (of Western Australia), the flow continuing around Cape Leeuwin and eastward along the south coast. In summer time this is reversed."*† Accordingly the drift of the early stage larvae (a surface phenomenon), hatched in the summer, should be northerly, while that of the late, returning larvae (also surface drifting) should be southerly. Considering the variations in the date of the egg hatching, the length of the larval life, and the surface drift effects at critical periods in the life-history, it is possible that

* Coun. Sci. Industr. Res. (Aust.) Div. Fish. Ann. Rep. No. 18 (1944).

† *Australia Pilot* **5** : 295 (1934).

hatching at the Abrolhos group could populate areas to the north and south of that point, while the Abrolhos group itself could be repopulated from both northern and southern areas at a considerable distance.

Jasus lalandii is associated with the westerly wind drift system, perhaps owing its circumpolar distribution to this fact, and the quite wide latitudinal range of *P. longipes* may be explained as consequent on the surface current movements already outlined. As at present very little is known of the surface and deeper water currents of the Western Australian shelf and slope, it is not possible to mark out the lines of drift of the larvae, although the point is of great importance in the maintenance of the fishery (see Section II. (f)).

The presence of juvenile crayfishes, of about the same size range (2 to 4 in. total length) in any one of many coastal areas during six to nine months of the year, is related to the lag which occurs in spawning at different parts of the range, to observed differences in temperature (the higher the average temperature, the more rapid, within limits, is the development), and to the resultant effects of the various currents. The moulting rate of these size groups has been tested, and is of the order of about once every six to ten weeks.

During larval development the life risks are those of ordinary plankton organisms together with a high risk from reef haunting predators in the early and late stages, and the risk of the animal being in an unfavourable environment at the time of the change over to a bottom-living habit. While the number of eggs produced by each female is high (from 100,000 to 250,000, depending on the size of the female) the mortality is also high.

(iii) *Juvenile and adult stages.*—As a general rule the smallest specimens are found in the shallowest reef areas, the size tending to increase as the water deepens ; coastal fringing reefs and their vicinity are usually the home of immature crayfish, although a small proportion of immature individuals is found at all depths. In areas such as the Abrolhos, and in heavily fissured reefs, the adults feed in shallow waters, retreating to deeper waters and fissures with the daylight. Small juveniles show a preference for areas rich in the seagrass *Cymodocea* and the green seaweeds *Ulva* and *Codium*.

While the species appears to be equally at home on granite, limestone, sandstone, or live coral reefs, specimens are rarely seen or captured on or near muddy silty bottoms ; they particularly avoid coral muds resulting from the erosion of dead coral reefs. The lee side of cliffs where wind-blown sands are deposited appears most unfavourable, for example, at Sandy Cape in the Jurien Bay area, which is very well populated, the crayfish occur only outside the wind-blown sand sectors. Barren, recently formed beach rock areas are likewise devoid of crayfish.

Size at onset of maturity as determined by the condition of the gonads is variable. Females have been found with a total length of $6\frac{1}{2}$ in. (carapace length $1\frac{3}{4}$ to 2 in.) carrying " berry " and with spent ovaries, while others have been taken up to a total length of $10\frac{1}{4}$ in. (carapace length $2\frac{3}{4}$ to $3\frac{1}{4}$ in.) with immature gonads. Males with ripe gonads occur at a minimum total length of 8 in.

(iv) " *White* " *crayfish.*—A feature of the fishery in the Rottnest Island area is the appearance of large numbers of crayfish varying in colour from a pinky red to parchment

yellow, during the early part of December. They are most plentiful in the sand areas adjacent to the coastal fringing reefs, are present during three to six weeks, and are regarded by some fishermen as a different species. During the 1947 season about 3,000 specimens were measured and examined. They proved to be newly-moulted specimens of *Panulirus longipes*, the common commercial crayfish. The carapace length ranged from $2\frac{1}{2}$ to 4 in., the modal, or most frequently occurring size class was $3\frac{1}{2}$ in., and males and females were nearly equal in numbers. The ovaries in the females were of the adult shape, but carried no residual eggs, although sections showed developing eggs closely packed in a pavement mosaic with some commencing to clump in tree-forms. The female openings at the base of the third legs were rudimentary. The testes of the males were likewise of adult shape but with no trace of milkiness. The male openings on the base of the last leg were rudimentary. Several hundred "pink" crayfish examined at the Abrolhos grounds during 1947 also possessed these characteristics.

The most likely conclusion is that these crayfish had just moulted into the mature condition and that the females would be ready for mating at the next moult, probably in July or August; that is, the specimens were virgin but approaching maturity. The conclusion is disturbing as the minimum legal length of $2\frac{3}{4}$ in., originally designed to give protection up to the period of first spawning, protects only about 15 per cent. of such ripening crayfish in the southern areas and about 50 per cent. in the northern.

The chief moulting seasons and number of moults per year in the larger sizes require investigation. Mass moulting of females, which have carried "berry" the previous season, occurs from January to March and April, while ripening females moult from July to August. Spent males moult from September to November, and ripening males from February to March. It is not suggested that an individual crayfish will necessarily moult at each period. The absence of ripening eggs in mature females taken without "berry," but showing traces of residual eggs in the ovaries, in the normal "berry" season suggests, as Herrick (1895) observes, for the true lobster (Homaridae), that egg-laying occurs every second year in *P. longipes*. This point, of great importance to any conservation scheme, requires confirmation.

(v) *Moulting, mating, and egg-laying.*—Successful mating, as shown by the presence of a recently deposited black spot (male sperm packets) on the sternum of newly moulted females, is general from July to September (rarely in June). To be successful mating must occur immediately after the moult of the female while the shell is still soft. The presence of a fresh black spot at other times does not necessarily denote maturity in the female but only that copulation has been attempted. A fresh black spot is seen all the year round on a certain number of hardshell females, indicating that some ripe males are present throughout the year. The eggs are extruded from late August onwards. Females are found carrying external eggs until at least the end of February in some years, but the bulk of the hatching appears to be completed by the end of January. Extrusion of eggs does not commence at the same time in the three island groups of the Abrolhos region, egg-laying commencing about a fortnight earlier in the Southern Group (Pelsart Island etc.) than in the Wallabi Islands about 30 miles northwards. In the third week of May 1947. two females in full "berry" were taken in a consignment of crayfish from the

Wallabi Islands. From time to time similar occurrences have been reported from various parts of the coast ; but the numbers concerned are very small.

The time of effective fertilization, and of egg-laying, varies greatly in different areas and is not constant for any one area from year to year. This is to be expected from the long period, varying between six and nine months, during which juvenile crayfish of a given size are to be found in any one area. Another result of this is that the interpretation of length and weight frequencies is difficult in the absence of cross checks such as are provided by the scale and otolith readings in corresponding work on the fish groups. Counts of the telson canals and spine rows and of certain of the carapace spine systems show decided groupings. These points are being investigated further in the hope that they may be of assistance in interpreting the length frequency figures.

At present, after examining the length measurement of about 18,000 carapaces, the most that can be said is that gonad maturity may occur from a little after the first year to the second year after the adoption of the crayfish form, and that the main impact of the fishery is on the first and second years of maturity, that is, on the late second, third, and early fourth years from the moult into the true crayfish form. This accords well with the findings of Nakamura (1940) on *P. japonicus*.

(vi) *Migration in the crayfish phase.*—While, as Von Bonde and Marchand (1935) suggested for the South African *J. lalandii*, the chief movements in the juvenile and adult may be random feeding wanderings, an apparently purposive movement across the Abrolhos area from a general north-westerly direction is evident during the latter part of the year, coupled with other movements on which successful fishery practices are based. The results, in 1947, of punch marking operations to test these points tended to confirm this opinion. In addition these results demonstrated that some mature males moved over distances varying up to thirty miles within two or three months and that the channels between the separate island groups presented no barrier (*see* Fig. 1.).

The occurrence of the so-called " White Cray," recently moulted virgin adults, in the shallow waters of the Rottnest Island area early in December, and of " pink " crayfishes in some of the Abrolhos areas suggests some form of post-moulting mass movement in those areas.

(*d*) *Geological and Geographical Environment*

(i) *General.—P. longipes* has been recorded from Cape Leeuwin in the south to at least North-West Cape in the north-west of the State, from latitude 34° 22′ to 21° 48′ S., a point-to-point distance of about 850 miles. From a little north of Cape Naturaliste to North-West Cape no granite reefs are recorded. Between the Bunbury area and the Murchison River are coastal limestones and the remains of eroded dune sandstones which form a complex tangle of onshore and offshore reefs, with the twenty-five-fathom line well defined. Large islands (Garden, Carnac, Rottnest) of this same material exist offshore in the general Fremantle area, with smaller islands at intervals northward. Onshore coral reefs of an earlier age are found at Bunbury, Rottnest Island, the Moore River, and at Point Leander, Dongara. A small, living coral reef is found at Rottnest ; elsewhere on the coast from Cape Naturaliste to Shark Bay there are isolated coral growths,

not of reef-forming dimensions, except perhaps at Wedge Island. Older limestones and sandstones occur between Red Point on Gantheaume Bay and the northern point of Dirk Hartog Island, a distance of about 135 miles. These cliffs are steep-to with deep reefs and rock ledges lying at various depths up to five to seven miles offshore.

The area between Shark Bay and Carnarvon possesses many reefs, sandbanks, and mud flats. Old limestone cliffs, steep-to, commence near Point Charles (now Quobba Point) running to about 10 miles northward of Red Bluff, then follow sandy beaches and recent limestone cliffs to Cape Farquhar and northwards nearly to Maud's Landing, a distance of about 35 miles. Ledges and reefs extend offshore from three to five miles with some sand bottoms present in the northern sector. Whether extensive coral exists on these reefs is not known. Older limestones with the lower terraces containing in places (*e.g.*, Yardi Creek) well-preserved fossil corals to a height of about forty feet, form the western side of the North-West Cape Range. Offshore, from below Point Maud to near Vlaming Head, a coral barrier reef on an old sandstone and limestone base lies offshore at a distance of from one to four miles, extending for about 60 miles. Shelter exists at Point Maud and Point Cloates, and the natural lagoons between the barrier reef and the coast although shallow are suitable for small-boat work. The shore side of the lagoons comprises dead coral terraces and mud flats. Stanley and Airey Pools are barren limestone-mud basins. Except at a few small reefs, the lagoons do not support crayfish populations on a commercial scale.

(ii) *Houtman's Abrolhos.*—These coral islands and reefs lie offshore in the Geraldton area between Latitude 28° 18′ S. and about Latitude 29° S., extending along an arc for about 50 miles at about 40 miles from the mainland. They cover some four to five hundred square miles of which only about 100 square miles are good shallow-water fishing areas. They are the centre of a crayfishing area developing in importance. Further details are given by Dakin (1919). (The *Panulirus penicillatus* of that paper (p. 174) is clearly *Panulirus longipes*). Recent descriptions of the islands are those of Teichert (1947), and Fairbridge (1948).

(*e*) *Population Controls*

General factors which operate against a high and stable crayfish population are :

(i) unfavourable currents at the time of the return of the puerilla stage ; (ii) a high predator pressure at all the stages ; (iii) environmental changes with poor adaptation of the species to the changing environment ; (iv) interspecific competition ; (v) intraspecific competition ; and (vi) unrestricted or badly managed fisheries.

This order does not necessarily indicate the order of importance.

(i) *Unfavourable current conditions.*—While there is some degree of adult mass movement, and while feeding wanderings are undoubtedly partly responsible for populating local grounds, the main dispersal phase is the larval period. Profound effects could be expected to follow a variation of current direction or strength during the critical period, namely, the lodgment of the surface floating puerilla. Continuous observation of the surface wind drifts together with observations as to the times of appearance of early and late stage larvae are required in order to assess variation due to this cause.

(ii) *Predator pressure.*—Among direct predators on *P. longipes* are several species of octopus, which capture the juveniles at all times and adults during moulting and egg laying, and the Abrolhos groper (*Choerodon cyanodus*). The larval stages are the prey of various plankton or part plankton feeders from the pilchard (*Sardinops neopilchardus*) to the Spanish mackerels (*Scomberomorus* spp., " albacore " of the Abrolhos fishermen), and various tuna species. The large numbers and the extent of the range of the species show that it has arrived at a favourable balance with its environment and with its predators. A question of great importance to the future of the species is, to what extent have fishing activities altered the species-predator balance ? In areas where the majority of the types of organisms present are fished, the resultant balance may not be altered greatly. In the Abrolhos crayfishery as in many fisheries the result of the operation is to reduce the number of one of the partners of a complex community in relation to the others. The effect on the balance is difficult to assess but it demands consideration in the working out of the management problem.

(iii) *Environmental changes and faulty adaptation.*—In a time sense, there are three main types of environmental change which can effect alterations in population or distribution characteristics. These are :

(1) Slow, almost imperceptible, unidirectional changes which proceed at such a rate that, over a long period, the total change lies within the limit of tolerance of the species. In the end the process may produce conditions under which the species cannot survive, but over a long period of the change population numbers and distributional characteristics may not be altered greatly. Slow, long term changes in the average temperature of oceans and seas belong to this class.

(2) Ebb and flow changes which proceed with a certain degree of regularity. In this case, population numbers tend to fluctuate widely and the area occupied will vary, depending on the amplitude and period of the change. An example is a wide seasonal variation of temperature in a marine environment.

(3) Short term changes, either unidirectional or of the ebb and flow type, which occur suddenly or irregularly. The general effect of these changes depends chiefly on their amplitude and may result in anything from a slight alteration in numbers to catastrophic extinction of the species. An example is the sudden change of direction of an ocean current so that it occupies areas previously dominated by water cooler or warmer than itself.

The genus *Panulirus* is limited to tropical and warm subtropical waters, while *Jasus* occupies cooler waters, so that temperature changes might be expected to prove a limiting factor with the genera, both as regards population numbers and the distribution of species. The species *P. longipes* extends to slightly cooler waters than do the majority of the other species of *Panulirus*. It is unfortunate that reliable water temperature records over a reasonable period are not available along the Western Australian coastal waters, but such figures as are to hand show that *P. longipes* as a species has a wide temperature tolerance ranging from a summer temperature of 17° C. at the south of its range to 28° C. at the north, and accordingly the species appears to be well adapted to stand a gradual change in the water temperature within wide limits.

Along the west coast of Western Australia the existence of fossil coral bands in cliffs and reefs as far south as Bunbury indicates warmer conditions with a suitable environment for this species in earlier times (*see* Teichert, 1947, pp. 186–190, for a fuller discussion). It is believed that, as short a time as 2,000 years ago, the sea-level was at least 10 feet higher than at present. Since then the sea-level has progressively dropped and at the same time the sea has grown cooler. It appears probable, therefore, that the environmental changes which have occurred are such as are described in the first part of this section.

An important question with regard to the stability of the Western Australian fishery is, has *P. longipes* successfully adapted itself to existence at a high and stable population density in this area, which has altered to a lower temperature, or is it colonising these cooler waters from the warmer part of its range ? No direct evidence of the presence of the species in these waters at the time of the building of the coral reefs has been obtained, but considering the geological age of the genus which dates from the Jurassic era, the present very wide distribution of the species, and the high dispersive powers of the larvae, it is difficult to imagine a suitable biological niche lying unoccupied in earlier ages, and, considering the wide temperature tolerance of the species, it should have had little difficulty in adapting itself to the subsequent temperature changes. Population fluctuations from this cause should not be great.

(iv) *Interspecific competition.*—Over the greater part of its range, *P. longipes* has no allied species as a competitor. Competition occurs only with *J. lalandii* in the southern area and with the four " coral " crayfishes in the northern part. Competition is direct with *J. lalandii* but it may not be so with the four northern species, as " coral " crayfishes appear to prefer old coral bottoms and coral mud flats and channels to a greater extent than does *P. longipes*, and may fill quite different ecological niches.

(v) *Intraspecific competition for food and shelter.*—During the investigation indirect evidence only was obtained of overcrowding in any particular area. This was inferred from the presence on the Dongara reefs and on some of the reefs at Rat Island, Abrolhos Group, of small crayfish whose internal development was more characteristic of specimens of a greater size elsewhere. In this respect the specimens resembled those taken in the Margaret River area in the extreme southern limits of the range.

(vi) *Unrestricted and badly managed fisheries.*—It is well known that equally favoured, extensive stocks of allied species in other parts of the world (New Zealand, South Africa, and France) have been seriously damaged in local areas by unrestricted or poorly managed fisheries. On the one hand there is the everpresent pressure to exploit an apparently unlimited resource and, on the other, the fact that the crowding together of the crayfish on limited feeding grounds renders their capture relatively easy. The greatest strain on the stocks comes when vessels equipped for the purposes of processing frozen tails invade areas which are suited rather for a less intensive fishery (see section on Recruitment of Stocks). At present the fishery in Western Australia is expanding. It is not known to what extent the ability to bear this expansion may be due to the presence of accumulated stocks which are certainly very high in previously unfished areas. The population density necessary to maintain the species is also unknown.

(*f*) *Natural Sanctuaries*

As stated earlier, long stretches of coastline are fronted by tangled reef complexes. Along some of these crayfishermen set pots close to the outer lines of breakers, but many square miles of grounds which are unfishable serve both as juvenile sheltering grounds and adult feeding or breeding grounds, depending on the depth. In the Abrolhos area, fishery on the steep-to, outer edge of the system is difficult and limited to very favourable weather periods. The risk of losing pots and boats there and on such reefs as the Turtle Dove shoals mean, in effect, that these areas are also naturally protected sanctuaries. (One test carried out on the 25-fathom line near the Turtle Dove Shoal yielded large crayfish, the recently moulted females showing the black spot of fertilization in May, a month earlier than in the Abrolhos group proper.) Such natural sanctuaries are scattered at intervals over the range of the species and, in view of the mechanics of the larval dispersion, their importance as contributors to the stocks of the fishable areas cannot be neglected. A further factor of value in the protection of the stocks of the fishery areas over a portion of the year is that very little fishing is possible in areas south of the Abrolhos during June, July, and August on account of winter gales and heavy seas. These months of natural protection cover a major moulting period and the fertilization period, and in those areas the management difficulties raised in other crayfisheries by the taking of both males and females at these critical periods do not occur. In addition the respite permits of some accumulation of crayfish of a suitable size on the fishing grounds.

The subject is discussed further in the notes on the regulation of the industry. At this stage it may be stated that the general indications are that the species appears to be well established over its range, that the population density is high, and that natural sanctuaries exist where puerilla lodge and from which many of the fishery grounds are re-stocked during the normal movements of maturing crayfish. These remarks do not suggest that local areas might not be temporarily worked out by intensive fishing (see Section III. 3).

(*g*) *Length and Weight Frequencies and Correlations*

Length measurements of about 3,000 specimens of *P. longipes* from known grounds in the Abrolhos area at monthly periods in 1942 and 1943 have been taken by Messrs. H. J. Murray, L. G. Smith, and N. W. Stathy of the State Fisheries Department, Western Australia. In June 1946, a commercial catch of 1,053 crayfish from a Rat Island ground was measured by the author. Beyond a preliminary scanning, these figures have not yet been analysed, but it is hoped that in conjunction with the measurements of about 18,000 specimens obtained during 1947, and 10,000 in 1948, they may give some indication of yearly growth and length, and weight correlations, and also afford a means of comparison of the characteristics of the population of various grounds. The results of the June 1946 measurements are entered as grouped data in the form of correlation tables, with males and females separated. The numbers in each table are different, as it was not possible to apply each of the three measurements, total length and carapace length and weight, to all the crayfish. The total length was measured from immediately behind the rostral horns to the rear edge of the telson or tail flap, using intervals of $\frac{1}{8}$ in. The carapace length was taken from immediately behind the rostral horns to the rear edge of the carapace in the mid-line, using intervals of $\frac{1}{16}$ in. Weight was measured at 1 oz. intervals.

TABLE 1

TOTAL LENGTH-WEIGHT CORRELATION TABLE

Weight

Mid-points—Ounces

		10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	Total Frequency
♂	8	2	2	1	1																6
648	8¼	1	12	7	4																24
	8½		11	16	13	7	1														48
	8¾		4	23	33	2		2													64
	9		3	15	39	22	11	3	1	2											96
	9¼			4	12	31	9	3	2												61
Total Length	9½				4	18	21	11	5	4	2										65
	9¾				2	4	19	10	5	3	2	1									46
	10				2		5	12	26	18	8	2	2								75
Mid-points—Inches	10¼				1	1	2	3	7	13	8		1	2							38
	10½				1				2	5	9	7	3	3	2	1					33
	10¾						1			2	4	2	6	3							18
	11										3	5	13	1	3	1	2				28
	11¼												1	3	3	2	1	1		1	12
	11½										1	1	3	1	1				1		8
	11¾												1	2	1	1	1	2	1		9
	12														2	1	1	2	1	1	8
	12¼																	5	1	2	8
	12½																	1			1
Total Frequency		3	32	66	112	85	69	44	48	47	37	18	30	15	12	6	5	11	4	4	648
♀	8		1																		1
	8¼		2	2																	4
310	8½	1	5	10	6																22
	8¾	1	8	13	17	1	3														43
	9		2	14	35	17	5														73
Total Length	9¼		2	1	19	12	4	1													39
	9½				15	18	4	2	2	1											42
Mid-points—Inches	9¾				2	7	7	3													19
	10				7	11	4	2	1	1	1										27
	10¼				1	5	9	4	2	1											22
	10½					1	5	3	1	1	1	1									13
	10¾							1	1			1									3
	11										1										1
	11¼								1												1
	11½																				....
	11¾																				....
	12																				....
	12¼																				....
	12½																				....
		2	20	40	102	72	41	16	8	4	3	2									310

Tables 1, 2, and 3 show the length-weight variation and the general type of length and weight frequencies of the commercial catch (June 18, 1946) of *Panulirus longipes* at Rat Island, Houtman's Abrolhos ; the reference figures are mid-points and represent smoothing by threes. The tables are published at this stage to show the length-weight variation and the general type of length and weight frequencies obtained from a commercial catch. Each table is subruled at the minimum legal length (carapace measurement 2¾ in.). Of interest is the very wide length-weight variation ; for example, at a

TABLE 2

CARAPACE LENGTH-WEIGHT CORRELATION TABLE

Weight

Mid-points—Ounces

		10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	Total Frequency
♂	2⅜		1	1																	2
646	2½	2		1																	3
	2⅝	1	7		3																11
	2¾		15	23	17	5	2														62
Legal Length—2¾ in.	2⅞		4	23	24	10		1													62
	3		5	15	51	28	18	6		3											126
	3⅛			1	9	19	7	3	1	1											41
	3¼			1	5	17	33	14	11	4	3	1									89
	3⅜					4	5	9	7	3	1										29
Carapace Length	3½				2	1	3	8	24	24	11	2	2	3							80
	3⅝						1		2	6	3	5	2	2							21
	3¾				1			2	2	4	13	3	6	1	4						36
Mid-points—Inches	3⅞					1		1	1	1	4	3	4	1	2	1					19
	4										2	4	13	7	4	3	3	2	1		39
	4⅛												1	1		1	1				4
	4¼												1	1				3	1		6
	4⅜															1				1	2
	4½												1		1		1		5	3	11
	4⅝																	1	1	1	3
Total Frequency		3	32	65	112	85	69	44	48	46	37	18	30	15	12	6	5	6	8	5	646
♀	2⅜		1																		1
♀	2½	1	1	1																	3
314	2⅝	1	1	1	1																4
	2¾		10	17	14	2	5	2													50
	2⅞		4	14	26	8	1														53
	3		3	6	45	27	5		1	2											89
Carapace Length	3⅛				7	11	7														25
	3¼				1	11	18	15	3			1									49
	3⅜					2	3	4				1	1								11
Mid-points—Inches	3½					2	1	3	6	2	1			1							16
	3⅝								1	3											4
	3¾										2	1	1		1						5
	3⅞								1												1
	4								1							1					2
	4⅛																				....
	4¼													1							1
	4⅜																				....
	4½																				....
	4⅝																				....
		2	20	39	94	63	40	24	13	7	3	3	2	2	1	1					314

carapace length of 3½ in. the male sample gave a weight range of 16 to 34 oz. By inspection this catch appears roughly typical of those from the average shallow waters of the Abrolhos area where the main impact of the fishery is on the total length sizes 8½ to 10½ in., carapace length 2¾ to 4 in., and weights 12 to 32 oz. The species can grow to a large size, as male and female specimens have been obtained weighing over 8 and 5 lb. respectively. The largest specimen reliably weighed was taken by Dr. D. L. Serventy at the Abrolhos, its weight being 8¾ lb., total length 17·8 in., carapace length 7·0 in.

(*h*) *Tagging and Marking Tests*

(i) *Tagging.*—Since all hard parts of a crayfish are shed at the moult, external tags fixed to those parts are of little use in helping to determine growth rates or in testing long term movements. Even in assessing population densities the results must be used with discretion as the factors underlying premoulting are still obscure, and, in spite of the selection of crayfish at a suitable stage, there is no guarantee that tags may not be

shed independently of the moult. However, the method is of some use both in population studies and for measuring local, short-term movements, although the tagging process is a very slow and difficult one under field conditions.

TABLE 3

TOTAL LENGTH—CARAPACE LENGTH CORRELATION TABLE

Carapace Length*

Mid-points—Inches

		2⅜	2½	2⅝	2¾	2⅞	3	3⅛	3¼	3⅜	3½	3⅝	3¾	3⅞	4	4⅛	4¼	4⅜	4½	4⅝	Total Frequency
♂																					
642	8	1	1	4																	6
	8¼		2	4	17	1															24
	8½	2		2	23	17	4														48
	8¾			1	16	27	18	2													64
	9				5	10	70	7	1	3											96
Total Length	9¼				1	7	20	15	17					1							61
	9½					1	10	11	31	7	4	1	1								66
Mid-points—Inches	9¾							3	32	3	2		1								41
	10								7	15	40	2	8	3							75
	10¼									1	27	7	1	2							38
	10½										7	9	13	2	1						32
	10¾											4	5	4	4						17
	11												5	7	15	1					28
	11¼												2		5	3	1		1		12
	11½														7				1		8
	11¾														4		4		1		9
	12														3		1	1	1	2	8
	12¼																	1	6	1	8
	12½																		1		....
Total Frequency		3	3	11	62	63	122	38	88	29	80	23	36	19	39	4	6	2	11	3	642
♀	8		1																		1
	8¼	1	1		1		1														4
314	8½		1	1	16	2	1														22
	8¾			2	21	16	4														43
Total Length	9			1	7	29	32		3	1											73
	9¼				1	6	23	4	4	1											39
	9½						23	9	6		4										42
Mid-points—Inches	9¾				4		3	9	7												23
	10							3	15		3		2		1						24
	10¼				1		1		9	7	2		1	1							22
	10½								5	1	6	1									13
	10¾											1	1								2
	11									1											1
	11¼										1	1	1								3
	11½																1				1
	11¾														1						1
	12																				....
	12¼																				....
	12½																				....
		1	3	4	51	53	89	25	49	11	16	3	5	1	2		1				314

* Legal Length—2¾ inches

Since it is unlikely that they would be shed at the moult, small celluloid and plastic tags used internally were tested with both *Jasus lalandii* in South Australia and *Panulirus longipes* in Western Australia. With *J. lalandii* the mortality was slight (9 in 167), although there was a tendency to shed the tag at moulting (17 in 46 moulting specimens). The mortality in *P. longipes* was high (53 deaths in 76), and when it was found that suitable punch-marks on the tail fan (telson and uropods) gave good results, the internal tag system was abandoned.

(ii) *Marking.*—Using lamb ear-marking pliers with dies of a suitable, simple pattern (diamond, heart, bar, circle, oval, and star), it was found that the design was readily identifiable up to and including the second moult after marking; in several cases it was discernible after the third moult.

(*a*) After first moult, 27 specimens, *P. longipes*. The space was either completely open or partly filled with the design clearly shown. This depended on whether the mark was made early or late in the intermoult.

(*b*) After second moult, 21 specimens, *P. longipes*. The space was filled, in two cases not completely, but the design was clear.

(*c*) After third moult, 8 specimens, *P. longipes*. In three cases, the design could be made out, in the others the outline was not clear.

Where filled in, the design was marked by paler colouring, absence of spines, and an alteration in the direction of the telson ridges and canals. The specimens were kept in slatted crates and many died when shedding their shell, particularly at the third moult. Growth was apparently not normal and in no case was the weight increment—the only measurement taken—more than four per cent. The results were promising enough to justify a long-range, large-scale marking test, in conjunction with a short-range, tagging test at the Abrolhos Group during the early part of 1947 (see Section IV. (*c*)).

(*i*) *Hatchery Prospects*

Although some success has attended the rearing and liberating of true lobster larvae (Homaridae), as Thompson (1934, p.16) points out in his general summary of the results, "protection of berried lobsters by law, under a good system of inspection, would achieve more results at less expense." It must be remembered that in the Homaridae the larvae hatch at an advanced stage, the period of larval life is short and the developmental series relatively simple. Owing to the long and complicated larval history of the Palinuridae, the hatching, rearing, and liberation of larvae do not appear to be practicable methods of replenishing supplies of crayfish of this family.

III. THE COMMERCIAL FISHERY IN WESTERN AUSTRALIA

(*a*) *Fishery Areas*

In spite of the extensive range of *P. longipes* the fishing grounds are grouped over relatively small areas. These are from south to north:

(i) General area .... Off Garden, Carnac, and Rottnest Islands
Port .... Fremantle
Market .... Fresh crayfish, Fremantle, Perth, and country. Frozen tails, overseas export.

(ii) General area .... Rottnest Island northwards, to off the Moore River and to Lancelin Island
Port .... Fremantle
Market .... As for (i).

Both areas are offshore deep reef fisheries (with a maximum depth of about 35 fathoms. They are chiefly a summer fishery (*see* Tables 4 and 5).

(iii) General area .... Port Denison onshore reefs
Market .... Local.

This is a small-boat shallow-water fishery on immature and small adult crayfish.

(iv) General area .... Geraldton, onshore fishery
Port .... Geraldton
Market .... Geraldton and country towns.
(v) General area .... Abrolhos Group
Port .... Geraldton
Market .... Cannery and as fresh and chilled crayfish, Perth, Geraldton, and Singapore. Frozen tails, overseas export.

This fishery is on shallow-water reefs, to a depth of about 10 fathoms. Although the Abrolhos Group covers about 400 square miles it is doubtful whether more than 100 square miles of this represents feeding grounds for crayfish.

From other areas small numbers are taken, mainly by amateurs, on coastal ledges at holiday places between Cape Leeuwin and Cape Naturaliste (Yallingup is possibly the chief of these) ; in the Jurien Bay area, around Sandy Cape and Green Head ; at holiday beaches north of Geraldton ; and at Point Charles (Quobba Point) north of Carnarvon. When the whaling station was operating at Point Cloates, consignments of *P. longipes* were sent to Carnarvon from Fraser Island on the Little Barrier Reef of North-West Cape Peninsula.

Reasons for the non-exploitation of other grounds are various :

(1) The general coastline is a lee shore with very few harbours or shelters.

(2) As the coast is open to the Indian Ocean swells, many of the reef systems cannot be penetrated from the sea in any but calm weather. Although vessels could be designed which could work under these conditions using pram or dory type dinghies to set the pots near breaker lines, as is done at present on a limited scale during summer months, the risk of pot and boat losses is great.

(3) While there are coastal areas such as those north of Jurien Bay which would yield a good return to a small-boat coastal fishery, the possibility of successful road transport is remote. Some forty miles of sand traversed by very few and very poor natural roads have to be negotiated before good roads to the railway towns, about forty miles further on, can be reached. The coast traverse is particularly difficult under winter conditions.

(4) In the region of Shark Bay and north of Carnarvon storage and transport are difficult, in addition competition from easily caught fish has hindered exploitation of crayfish populations in such sand-free areas as exist there. Storage presents problems as both well-boat and floating-crate storage are not efficient in warm seas. Crates can be maintained safely only in reasonably calm shelter, and in such a position in warm seas oxygen is rapidly used up and its replacement is slow. The factors involved in storage of live Crustacea are well set out in Chaisson (1932). On-the-spot refrigeration is probably the answer to this problem and should the fishery on schooling fish decline, a quick-freeze crayfishery might develop, particularly off False Entrance, south of Shark Bay.

(5) The Little Barrier Reef area of North-West Cape is not well known to fisherman. There are indications that *P. longipes* and three other species, *P. ornatus*, *P. versicolor*, and *P. penicillatus*, occur in reef areas seaward of the lagoon, and at times in such lagoon areas as are mud-free.

(*b*) *Fishery Practice*

(i) *Catching methods.*—The industry is exclusively a pot fishery. Cane or spearwood beehived-shaped pots are used in the Garden Island, Rottnest, and Moore River deep fishery areas. On the Abrolhos grounds rectangular hardwood batten pots are used, with some cane pots in deeper waters. Both the hardwood and cane pots are very durable but are open to the objection that once they break away from their ropes they may act as crayfish killers, crayfish entering them acting as bait for fresh arrivals. Both types of pots require much ballast because of their buoyancy, and their liability to under-water movement. Consequently pulling and transport are not easy.

An easier pulling pot which would not present such a potential menace once it had broken from its ropes has been devised and tested by Messrs. J. Baseden and R. Page of Geraldton, and the author. This is not as efficient as the batten or cane pot, but is light to pull, is stable under water, and transport is easy. If the pot is lost the bottom breaks away within a month or so. The pot is a flat-topped beehive with 15 ribs of 6-gauge wire or so which a continuous spiral of 8-gauge wire is spot welded, using an electric welder, leaving 2 in. between each round. The pot is galvanised after welding. The height is 16 in., diameter 37 in., with a neck opening of 9 in. tapering to 8 in. over a neck length of 9 in. The bottom is made separately with 8-gauge wire rounds spot welded on 30 radial ribs of 6-gauge wire. The separation renders transport simple as the bottomless beehive tops nest into one another, with the bottoms carried separately. In use, the bottom is wired to the beehive top with 16 or 22-gauge wire. This rusts through fairly readily and must be renewed during the season ; if the trap is lost it becomes quickly inoperative.

In a recent (May 1947) heavy blow in the Abrolhos area none of the 35 wire pots set in areas exposed to the very heavy breaking swells was lost. Very few moved from their lines. Other fishermen in the area reported losses and a general drift of cane and batten pots set in more sheltered waters.

For deep-water fishery on the southern spiny lobster (*Jasus lalandii*) the dimensions of the pot should be :

Height—about 18 in.
Diameter—40 to 42 in.
Neck opening—10 to 11 in.
Neck length—6 in., no taper ; throat lined with cane.
Wire—4 and 6-gauge.

In addition, the outer ring of the bottom should be of $\frac{1}{4}$ or $\frac{3}{8}$ in. iron. All galvanised after welding.

Jasus lalandii is fished at a larger size (2-6 lb.) than *P. longipes* (1-3 lb.). In addition *J. lalandii* with its stouter legs and relatively broader body demands the wider-necked pot for efficient fishing. The stronger pot construction is required because of the greater bottom movement in southern waters, and the greater strain imposed by haulage from the deeper waters (up to 40 fathoms). The batten pots are suitable for calm shallow waters, the cane or spearwood pot for open-sea work in calm to moderate seas, and the wire pot poor conditions in unsheltered seas. If the upper part of the beehive is laced with spearwood or cane, the wire pot compares well with any other type.

The bait used, cow heel, rabbit, sheep's head, fish or shark, is hung with either fixed wires or toggles from the top of the pot, or suspended from a stick thrust from the side of the pot to the neck mesh. With the wire pots the bait is wired or toggled closely to the inside of the neck. The rope line is floated free from the bottom with corks, with a cork or glass bubble trailer at the surface. Pots are set in lines of five. Hauling is done by hand in Western Australia, but an upright disc winch run from the engine is used to some extent as a hauling drum in other States. In the Fremantle area the boats, ranging from 33 feet to 45 feet and working 30 to 50 pots, leave port each day for the grounds, up to 40 miles away, haul and rebait the pots if necessary and transport the catch direct to Fremantle. The pots are left overnight. Both the Dongara and Geraldton fisheries are daily runs with smaller boats and a smaller number of pots.

In the Abrolhos two main systems are used. Firstly, the boats (25 to 50 feet long, working 30 to 60 pots), owned in shares or by family groups, make regular 10 to 14 day trips to the islands, the crews fishing both for crayfish and fish until the load is complete. Secondly, the boat acts solely as transport for the catch. The catchers reside on one or other of the islands for the season.

(ii) *Storage and transport.*—In the Fremantle area the crayfish are held in pierced wells in the boats although some of the catch is bagged. This method is possible on daily runs. At the Abrolhos, crayfish awaiting transport are stored in slatted crates floated from pontoon stages at anchorages in the islands. When required, the crayfish are bagged, stacked in and on the boat out of the wind, and transported to Geraldton. Three-bushel wheat bags, holding from five to seven dozen crayfish, are used, the crayfish surviving from 24 to 36 hours, depending on the care in stacking and handling. Boats transport from thirty to one hundred and fifty bags at a time, according to the loading space available.

Part of the catch is canned at Geraldton, and part is treated there for the frozen tail export market. A road transport service also operates carrying both fish and crayfish to Perth in refrigerated chambers maintained at a temperature of 18°F. The journey occupies from 10 to 12 hours for the 320 mile trip.

(iii) *Fishery conditions, Abrolhos Group.*—Working areas, till 1946, were allotted by mutual agreement and squatters' rights since the small number of fishermen engaged permitted the arrangement. With the small number of fishermen operating, the grounds were fished for periods and then were left for a while, without interference, to recover. As a result the proportion of small ($2\frac{3}{4}$ in.) crayfish marketed was reasonably low. With more and more boats coming into the industry there has been a tendency for fishermen to work for an increasingly longer period on the same set of grounds, and the smaller size-groups of crayfish are marketed in increasing quantities, while in most cases the original system of amicable partition of fishing areas is not maintained. Some areas of the fishing grounds became overcrowded with fishermen early in 1947 when prices rose steeply in response to the demands of the export markets. Foreseeing this the State Government amended the State Fisheries Act in 1946 to give the Department concerned the power to license boats for particular areas. The application of this rule was made with the co-operation of the fishermen. In spite of this, some areas were over-fished during 1947.

Crayfish are reasonably accessible to the fishery over relatively limited areas of the Abrolhos Group, owing in part to the presence of large areas of dead coral and eroding limestones where there are no crayfish, and in part to the very inaccessible tangle of shallow reefs which occupy much of the actual interisland waters. West of the islands the depth drops rapidly to 50 or 60 fathoms and the very heavy and constant swells render crayfishing very hazardous. East of the island the depth is less (about 22 fathoms) but the seas are lumpy and the risk of losing pots during even moderate blows is great. Although hazardous, fishing is possible with properly designed gear. Fishing tests in the above areas during 1947 indicated the presence of crayfish of all the sizes normally taken on the fishing grounds with, in addition, some crayfish running to four and five pounds.

(c) *Recruitment of Stocks, Abrolhos Group*

Fishery practice, field observations over the past two years, the results of marking tests in 1947, and continuous fishing tests during 1947 and 1948, suggest that the crayfish taken in the Abrolhos shallow-water areas are derived from five sources, in a time sequence during the season as follows : (i) The population which has accumulated during the previous closed season, (ii) movement from reef fissures and holes adjacent to the shallow-water areas of crayfish which for one reason or another did not occupy those areas during the closed season, (iii) movement from deep-water areas immediately surrounding the shallows, (iv) a general movement of crayfish, as they approach maturity, from the outer, deep-water reefs to the live coral, shallower feeding grounds (this occurs throughout the season), (v) general movement, attaining almost the status of a migration, and roughly from the north-west, of mature crayfish, particularly of females with ripening ovaries. This movement commences in June and July and is at its height in August and September.

These factors apply to the short term (seasonal) replenishment of shallow-water areas, and it is understandable that intensive fishing might temporarily deplete such areas. If the last three movements are not prevented or reduced by fishing in the deep water between, and to the west of the main island groups, the position rapidly rights itself. Such conditions of short term, as opposed to long term, overfishing were apparent in some of the readily accessible Abrolhos grounds towards the end of 1946 and during 1947.

To restate the position, it would appear that the crayfish are tending to move during the season toward the shallow-water, live-coral, and seaweed areas. The removal of crayfish at those places through a fishery extending over the season at a rate equal to, or less than, the rate of replacement does no harm ; if the fishing rate is greater than the rate of movement a temporary dearth of crayfish results, but as soon as the catching pressure is released the grounds restock ; if the outer, deep grounds are fished, replenishment of the shallow-water areas is retarded. During 1946 and 1947 some of the Wallabi and Rat Island grounds yielded low returns toward the end of the season and fishermen found it necessary to move their pots frequently, and over greater areas of ground, in order to maintain their catch figures.

The general long term replenishment of an area occurs during the late larval stages of the species. Planned tow-netting experiments, continued over a number of years, in conjunction with observations on the nature of the wind drift currents, are required in order to assess the factors involved in this.

(*d*) *Regulation of the Fishery*

Among other aims, regulations governing a crayfishery should be framed to ensure that reasonable brood stock is available, that breeding females may spawn or hatch their eggs, that a crayfish is not taken until it has reached a size at which the proportion of flesh weight to total weight is highest (in *P. longipes* this occurs over the carapace length range 3-4 in.), and that sanctuaries are reserved, thus enabling undisturbed growth of immature crayfish and providing centres of distribution both of adults and larvae.

The regulations in force in Western Australia in the crayfishing industry are :

(i) *A minimum size length.*—This is a carapace length of $2\frac{3}{4}$ in. ; measured from the rear end of the base of the rostral horns (the enlarged supra-orbital spines) to the rear end of the carapace. In this regulation the rostral horns are regarded as marking the rostrum, and " the rear end " means the rear margin of the base of these horns. The weight equivalent of this carapace length is 10-16 oz., the total length being equivalent to 8-9 in. Protection is given in part to females at the first spawning, which may occur from a total length of $7\frac{1}{2}$-$10\frac{1}{2}$ in., carapace length $1\frac{1}{2}$-4 in., and the regulation also aims at ensuring that the crayfish is not taken before reaching a size giving reasonable return in weight of flesh.

The general tendency of a fishery on a species, where little migration of the adults takes place is for the sizes of the fish taken progressively to approach the permitted minimum. Under the pressure of intensive fishing this position is being reached (1948) at some of the Abrolhos grounds, particularly, at Rat Island. Herrick (1895) discusses the possibility of using a double gauge law to ensure the maintenance of an adequate spawning stock. No such provision of both a minimum and maximum size is made in Australian crayfishery regulations, but in the Abrolhos fishery it would appear that, arising out of the limited intensity of the fishery, the same result was arrived at prior to 1947, as there appeared to be a considerable escape of large crayfish (3-4 lb.) to deeper water up to 1946. Since then, fishing pressure on the shallow waters has been intensified and the possibility of escape reduced ; in addition, there has been a considerable extension of the fishery to deeper waters (15 to 25 fathoms).

(ii) A prohibition exists on the selling or possession of a female having eggs attached, or which has been captured with eggs attached. This is designed to protect the female over the egg-carrying and hatching period and to ensure a reasonable release of larvae. While the protection is a good one for crayfish taken up to a depth of about 10 fathoms, tests show that only about 20 per cent. of eggs from fish taken at a greater depth hatch, as compared with 70-80 per cent. from females taken in shallow water. In addition, only about 50 per cent. of the females hauled from the greater depths have survived in the normal storage crates. Perhaps the rapid alteration of pressure during the hauling of the pots from the greater depths has an adverse effect.

(iii) A closed season was created in 1946, protecting the crayfish during the spawning and " berry " period in the Abrolhos area defined as follows :

> " In that portion of Western Australian waters lying south of 28° 15′ S. and west of 114° 10′ including the waters surrounding the islands situated therein from 1st October to 15th February."

In 1946 the fishermen were given until October 15 to complete their trips. The 1947 season opened on March 1 and closed on September 30. The 1948 season opened on March 15 and closed on August 31. An effect of this closure, of great importance, is that it permits accumulation of stocks on the fishing grounds.

(iv) No regulations govern the establishment of sanctuaries but, as detailed earlier, the inaccessible nature of many coastal areas under present fishery methods in effect creates large areas of well spaced sanctuaries. It is desirable to close some of these areas before crayfisheries develop there.

(v) No direction or regulation exists on the minimum spacing of the laths of batten pots, the canes of the cane or woven pots, and the wires of the wire pots. A minimum spacing should be provided for the distance between the lower side and end slats and the bottom, as is the case in the Newfoundland lobster fishery, in order to assist in the escape of immature crayfish from the pots during and before hauling and thus to minimise damage to crayfish of these sizes (Templeman 1939). A space of 2 in. would permit the escape of immature *P. longipes* and retain those of the minimum size.

(vi) There is also no regulation governing the number of crayfish which can be taken off a particular ground. In the past, economic conditions and the limitations imposed by the fishing methods ensured that grounds were not stripped bare, but with rising prices and more efficient fishing methods some form of restriction may become necessary.

Fishing to supply crayfish tails only is developing. The crayfish tails are quick-frozen near the point of capture and are then transported in that state to the consumer. The system has certain short range economic advantages and is a useful one for exploiting accumulated stocks on grounds not previously fished, such as those in the Lancelin Island, Jurien Bay, and Beagle Island areas. As supervision is extremely difficult, and the method results in very intensive fishing, the repercussions on the management of a limited fishery based on an annual renewal, such as that of the Abrolhos Island, may be great. The alternative to local, or to unsupervised processing, is to transport the live crayfish to a common centre (as occurs in the Fremantle and Abrolhos areas at present) for inspection and processing. This does away with some of the economic and technical advantages of the local processing method ; but ensures that all fishermen observe the protective regulations, and tends to slow the fishing rate down more closely to the replacement rate of the larger crayfish, thus relieving the fishing pressure on the smaller size-groups.

(*e*) *Statistics*

Western Australian catch, gear, men, and boat records are of little value prior to 1941. Yearly totals from 1901 to 1932 show landings ranging from 6,000 to 16,000 dozen crayfish annually. These are small by comparison with present-day catches. In 1941, Mr. A. J. Fraser, Chief Inspector of Fisheries, Western Australia, instituted a block system of recording landings, gear, boats, and time worked, and although these figures are of limited value over the war years when especial conditions and limitations applied to the crayfishery, they demonstrate the rapid growth of the fishery.

Yearly landings from 1941 to 1948 in pounds were :

	Abrolhos	Geraldton	Dongara	Fremantle	Total
1941	224,148	82,400	25,204	150,100	481,852
1942	130,092	63,516	17,724	15,924	227,256
1943	360,876	76,944	16,152	16,604	470,576
1944	518,261	59,556	12,153	16,646	606,616
1945	511,831	83,647	12,843	155,675	763,996
1946	895,123	114,612	15,781	237,156	1,262,672
1947	1,467,729	106,956	12,000	840,561	2,429,372
1948	1,321,811	307,446	24,222	1,184,533	2,838,012

In 1946 the landings of the crayfish *P. longipes* represented about one-quarter of the fish production of the State on a weight basis, and in 1947 about two-sevenths. The increased catch from the Fremantle area in 1947 and 1948 was due largely to the extension of the fishery northwards to Lancelin Island. A shorter catching season operated in the Abrolhos area during 1948.

The live weight of crayfish from the Abrolhos grounds, treated at Geraldton Canneries Ltd., were :

1943 .... 297,000 lb.
1944 .... 470,000 lb.
1945 .... 497,000 lb.
1946 .... 791,000 lb.
1947 .... 902,041 lb.

The 791,000 lb. treated in 1946 yielded 390,000 7-oz. cans of craymeat.

TABLE 4

COMMERCIAL CATCH, *PANULIRUS LONGIPES*, 1945.

Month	Abrolhos	Geraldton	Dongara	Fremantle	Moore River	Total
	lb.	lb.	lb.	lb.	lb.	lb.
January	....	8,396	1,176	13,528	16,057	39,157
February	16,603 (2 weeks)	9,164	497	6,738	15,584	48,586
March	40,497	12,607	732	9,753	9,794	73,383
April	59,712	6,532	695	177	955	68,071
May	81,153	3,092	216	46	300	84,807
June	23,488	2,816	420	....	....	26,724
July	63,722	8,301	983	....	....	73,006
August	109,091	4,127	1,307	....	....	114,525
September	77,799	5,718	982	....	....	84,499
October	39,766 (2 weeks)	5,601	1,323	5,364	5,183	57,237
November	....	5,634	1,936	11,241	14,576	33,387
December	....	11,659	2,576	23,714	22,665	60,614
Totals	511,831	83,647	12,843	70,561	85,114	763,996

The monthly figures for each area for 1945 and 1946 are given in Tables 4 and 5, supplied by the State Department of Fisheries of Western Australia. Table 6 records the crayfish landings for 1944, 1945, 1946, and 1947, from the States of New South Wales, Victoria, Tasmania, and Western Australia, as supplied by the respective State Fisheries Departments. Figures from South Australia are not available, but the general indications are that the annual catch is in the vicinity of 1,000,000 lb. The following comments may be useful in interpreting Tables 4 and 5.

(1) *Abrolhos area.*—The open season during 1945 and 1946 lasted from the beginning of the last fortnight of February to the end of the first fortnight of October.

The weight of the catch for March, April, and May depends on three main factors :

(i) The progressive increase during the season of the number of boats working,

(ii) The effect of the post-spawning and main male maturity moults, and

(iii) The increasingly better fishing weather.

TABLE 5

COMMERCIAL CATCH, *PANULIRUS LONGIPES*, 1946.

Month	Abrolhos	Geraldton	Dongara	Fremantle	Moore River	Total
	lb.	lb.	lb.	lb.	lb.	lb.
January	....	7,994	626	12,968	17,668	39,256
February	24,297	7,439	688	6,637	24,876	63,937
March	90,504	10,769	745	4,369	24,090	130,477
April	97,613	9,861	730	12,940	10,084	131,228
May	141,678	8,717	1,628	1,862	9,021	163,906
June	94,856	5,705	1,318	1,001	545	103,425
July	67,452	5,825	1,136	....	226	74,639
August	184,677	7,855	2,408	....	200	195,140
September	139,311	10,823	2,460	9,356	7,568	169,518
October	54,735	14,887	1,272	11,444	10,689	93,027
November	....	5,886	1,270	21,091	10,774	39,021
December	....	17,851	1,500	24,919	14,828	59,098
Totals	895,123	114,612	15,781	106,587	130,569	1,262,672

Relatively low figures for June and July reflect unfavourable mainland to islands crossing and fishing weather, together with some cessation of crayfish feeding wanderings due to the onset of the main adult female moult plus the following period of mating. July and August are the months of highest feeding activity. " Berried " females appear during September and onwards and are released from the catch. Occasionally they are taken earlier but the numbers are small.

(2) *Other areas.*—The figures for the open sea, unsheltered areas reflect very well the prevailing weather.

(f) Conservation

This subject has been referred to in earlier parts of this paper but a general summary of the position is required. There are two very different aspects of the problem. One concerns the management of the fishery to ensure an adequate yearly lodgment of young crayfish at the accessible grounds, the other to ensure that in each season the highest weight of flesh can be otained from the gross live weight of captured crayfish.

TABLE 6

CRAYFISH PRODUCTION IN AUSTRALIAN STATES.

Date	N.S.W.	Tasmania	Victoria*	W.A.
1944–45	235,440	344,603	....	....
1945–46	256,544	1,675,860	....	....
1946–47	276,503	2,213,048	....	....
1944	....	....	300,132	606,616
1945	....	....	346,852	763,996
1946	....	....	255,102	1,262,672
1947	....	....	353,600	2,429,372

Species fished :

New South Wales : *Jasus verreauxi* and *J. lalandii.*
Tasmania, Victoria, and South Australia : *Jasus lalandii.*
Western Australia : *Panulirus longipes.*

* An unknown quantity of crayfish landed at ports in West Victoria is taken from grounds along the south-east coast of South Australia.

(i) *Lodgment of larvae.*—Examination of the catch records of individual fishermen with respect to their catch, number of pots, method and time of working, and areas worked, does not suggest that, over the past ten years, there has been any high degree of fluctuation in the numbers of crayfish which lodge yearly. Consequently it should be a safe practice to ascribe any future diminution of the over-all yearly catch per unit effort (catch per pot, catch per fisherman, catch per unit of time, or of some other standard measure) to an actual diminution in the total population. The present minimum size does not adequately protect the crayfish at maturity ; the area fished and the number of fishermen engaged are increasing ; and boats, gear, and methods are becoming more efficient. From a study of the history of crayfish and lobster fisheries in other countries it is apparent that a condition of overfishing or even of depletion may occur with little warning under such conditions.

(ii) *The optimum catch.*—The Western Australian crayfishery falls into three major sections. The first is the Abrolhos fishery. The second is the offshore coastal shelf fishery which is operated in depths ranging from 10-30 fathoms at intervals along the coastal shelf from off Garden Island in the south to off Port Gregory in the north, a straight-line distance of about 300 miles. The third consists of a group of shallow water (5 to 10 fathom) fisheries on areas adjacent to coastal reefs. Dongara is the chief representative of this group. Each of these groups presents a different problem in management.

(1) *The Abrolhos fishery.*—The crayfish are taken in this area during the season (March to September) from the following sources. In the first part of the season (March to June) from the stock which has accumulated on and about the feeding grounds during the closed season. This includes non-moulting, mature crayfish which would normally breed in the next season ; recently moulted, soft and weak crayfish, the breeders of the past season ; and a proportion of immature crayfish which would normally moult at intervals throughout the year. In the second part of the season (July to September) the individuals captured are principally females which have moved to the shallows for intensive feeding while ripening their eggs ; immature crayfish, which have moulted several times during the period, and which have attained the legal size ; and mature males which have occupied the shallows for feeding purposes, following on the June and July mating period. The management problem involved is how best to harvest this changing and growing crop so that the best weight of flesh in the best condition is taken from the grounds during the fishing period.

Recently moulted crayfish are weak and do not transport well. They contain a high percentage of water in the flesh and the loss in weight through water loss during processing is 10 to 15 per cent. In 1948 the State Department endeavoured to protect these crayfish by delaying the opening of the season until March 15, by which time the bulk of the crayfish of this group should have passed through the moulting period. The measure was only partly successful, as a long period of calm, hot weather occurred, lasting unseasonably until the beginning of April. The mortality in the newly moulted crayfish during transport was high.

The size group which gives the best return in flesh recovered, and transports the best, lies between a carapace length of from 3-4½ in. providing the crayfish are mature and firm shelled. Below and above this size the total weight of recoverable flesh is less in relation to the weight of the whole crayfish. The best weight of flesh can be taken only if the fishery is a continuous process during the open season operating progressively on the growing stock, and is so conducted that size groups under 3 in. are permitted to reach at least that size. This implies that intensive, highly efficient fishing methods may give very wasteful results in the Abrolhos area.

Market sampling was carried out during 1947 on the Abrolhos crayfish and, in all the areas there, it was found that the modal size class (the size group containing the most individuals) of the commercial catch was reduced toward the minimum legal length (2¾ in. during the season. Since immature crayfish of the size range 2½-3 in. undergo several moults during this period, with an increase in tail size at each, it is obvious that the weight of flesh taken during the year fell short of that which could be taken from the same number of crayfish if taken at or after the larger size. The difference in weight of flesh between a mature crayfish of 2¾ in. carapace length and one of 3 in. is 1½-2 oz. and the flesh weight difference between an immature crayfish of 2¾ in. and a mature one of 3 in. carapace length is 2-2½ oz., so that the weight loss by taking the smaller crayfish may be very high in the total fishery. For example, at the Rat Island grounds in 1947 the total numbers sold were about 600,000 individuals. Of these over 60 per cent., or about 400,000 individuals, were in the 2¾ in. size group. This represents a possible weight loss of about 50,000 lb. of flesh. Other areas had been less severely fished back toward the minimum length, so that the total number of about 1,500,000 individuals of the 1947 fishery represented about 500,000 in the 2¾ in. size group, a possible flesh loss of about 60,000 lb. to the 1948 fishery.

The number of fishermen engaged in catching during 1947 varied between 33 and 43, and the number during the first part of 1948 was 55. A comparison between the results of April 1947 and April 1948 is of interest. In April 1947, 33 fishermen captured 206,909 lb. of crayfish, giving a catch per man of 6,269 lb. In April 1948, 55 fishermen captured 266,223 lb. of crayfish giving a catch per man of 4,840 lb. The fishing intensity remained at this relatively high level during 1948, but the commercial market samplings indicated that crayfish were of a larger size than in 1947. This was due to the shorter season and to the extension of the fishery to previously unworked areas both within and outside the shallow-water gounds. It is doubtful whether the improvement due to the latter cause will be permanent since marking tests during 1947 indicated that during July, August, and September there was a considerable movement of crayfish from the deeper waters to the shallower grounds. Any great extension of the fishery beyond the shallow water feeding grounds, particularly to the channels between the island groups, will ultimately affect the catch on those grounds. It is however, good practice to remove the accumulated stocks of old, large crayfish from hitherto unfished reefs within the shallow-water areas, and considerable fishing of this type has occurred at the Abrolhos during 1948.

The size composition of representative pot-catches taken at the main groups of Houtman's Abrolhos during 1947 is of interest in this regard. The figures are given in Table 7.

TABLE 7

SIZE DISTRIBUTION POT CATCH 1947, *P. LONGIPES*, ABROLHOS GROUP

Locality	Number	Mean (in.)	Modal Class (in.)	Range (in.)	Per cent. below $2\frac{3}{4}$ in.
Rat Island	2,101	2.5	$2\frac{1}{2}$	1.9–4.5	57
Southern Group	4,692	3.3	$3\frac{1}{4}$	1.9–5.5	10
Wallabi Group	2,683	3.0	3	1.9–4.8	34

The destruction of under-size crayfish in the catch is high, due to mishandling, exposure to sun and air, and use as bait. The loss of flesh weight in later catches is undoubtedly higher in the more heavily fished than in the more lightly fished area. This is particularly evident among the females, of which the $2\frac{3}{4}$ in. size group comprised 72 per cent. in the Rat Island commercial landings during 1947, compared with only 13 per cent. at Southern Group.

Detailed population tests using marking and recapture methods were carried out at the Abrolhos during 1947. The results, which are being analysed on methods based on American pond population work, will be reported elsewhere. At present limiting values only can be given. These apply to the period April to May, and suggest that, over a size range of 1·9 to 4·5 in., the population of the Southern Group lay between 600,000 and 900,000, that of the Easter Group 1,500,000 to 2,000,000, and of the Wallabi Group 1,000,000 to 1,200,000, giving total values lying between 3,100,000 and 4,000,000. Using the pot-catch percentages above, these figures reduce to limits of 350,000 to 700,000 legal size crayfish for Southern Group, 600,000 to 800,000 for the Easter Group, and 600,000 to 700,000 for the Wallabi Group. This yields possible total limits for the shallow areas of 1,500,000 to 2,000,000, of which 400,000 to 700,000 would be in the $2\frac{3}{4}$ in.

class interval. These figures were calculated following on surveys which indicated that during 1947 the area representing the actual fishing grounds in the Southern Group was 36 square miles, in the Easter Group 40 square miles, and in the Wallabi Group 35 square miles. As there are some barren limestone mud areas within these limits the figures may be over-estimates. The population figures do not take into account the July to August movement of crayfish from deeper outside waters. Continuous fishing tests during 1947, indicated that this movement may involve 20 to 30 per cent. of the population present before June.

The actual catch for 1947 was about 1,400,000 lb. which represented about 1,300,000 individuals. It is significant that as the season progressed the modal size steadily declined so that 70 per cent. of the August-September catch was composed of the size-groups $2\frac{3}{4}$-$3\frac{1}{4}$ in., as compared with 55 per cent. during the period May-June. In addition, the size groups over 4 in. had virtually disappeared from the later catch. Figures supplied by fishermen indicate that this was not the case in earlier years. The decline occurred in spite of the fact that growth continued during the period. It is fair to assume on this basis that the commercial catch for 1947 was closely related to the actual population above the legal size present on the fishery grounds, and that the limits given above were reasonable approximations to this population, with the upper limit set too high.

As the season progressed an increase in the number of under-sized crayfish captured in the pots was noticeable. This does not necessarily indicate any increase in the number of small crayfish, but indicates that the absence of large crayfish, particularly of the more aggressive males, permitted the small crayfish, normally present, to enter the pots.

During 1948 the crayfishing season at the Abrolhos Group was restricted to the period March 15 to August 31, while fishing boats which had operated previously below latitude 30°S. were not permitted at those islands. The number of fishermen primarily engaged varied between 60 and 44 and the catch for the season was 1,321,811 lb. (subject to several outstanding returns). At the request of the fishermen these restrictions have been re-imposed for the 1949 season, the permissible catch being restricted, also, to 1,500,000 lb.

Although the work is still in progress, sufficient has been done to suggest that the population available on the shallow water grounds is limited and that extension of the adjacent deep waters may react to the detriment of the shallow-water fishery. The work also points to yearly captures of between 1,300,000 to 1,500,000 crayfish as being the maximum limits if the fishery is to continue for a period of years without forced closure for restocking, and suggests that the lower limit is preferable. It must be remembered that in this fishery the individuals as a group do not pass out of reach of the fishery as they grow, but remain to be caught, so that the principles involved in the management of the Abrolhos shallow-water fishery are those of ordinary stock farming management.

(2) *The coastal deep-water fishery.*—While the Abrolhos fishery is one on shallow-water grounds where both the juveniles and adults inhabit the same general areas, the coastal deep-water fishery is mainly on adults from their first year of maturity onward. The reason is that the incoming larvae lodge chiefly in the shallow-water coastal reef systems

which are to a large extent inaccessible to fishing. So the crayfish captured are of reasonable economic size while there is little fishing pressure on the growing juveniles, which eventually move to the deeper waters in sufficient numbers to restock the fishing grounds. Considerable protection is given by stormy weather to the southern population during the winter months and to the northern population in summer months. This means that the northern population (from Jurien Bay, northwards) is naturally protected during the period when the female is carrying "berry," and the southern population during the winter months when the ovaries are ripening. During the "berry" season in the south, which is also the fishing season there, it may be necessary to give a fuller protection as the general fishery expands. This protection could take the form of a closed season during December and January, excepting perhaps the southern "white crayfish" grounds during December.

In some areas, *e.g.*, Lancelin Island, crayfisheries have developed to exploit the extensive accumulated stocks by means of freezer boats on which the crayfish, supplied by smaller units, are processed as frozen tails. Since it is good practice to remove a high percentage of this accumulation, particularly of crayfish 4·5 to 5 in. carapace length and upwards, little or no supervision is required at that stage. However, after two years of increasing effort at these areas there are indications that the greater part of the original stock has been removed and that the fishery is depending upon the annual increment with a proportion of immature crayfish from shallower waters. It is not good practice to remove the latter, accordingly more careful management will be required in future seasons.

(3) *Shallow-water coastal reef fisheries.*—The chief of these is centred at Port Denison, Dongara, where there is a small fishery on the late juvenile and immature crayfish. No fishery exists on the associated deep-water areas so that the position is the reverse of that of the deep-water fishery from Garden Island to Lancelin Island, in that the crayfish pass beyond the reach of the fishery, instead of passing into it as they mature. The position in the shallow-water coastal fisheries resembles to some extent that of the fishery on immature mullet (*Mugil dobula*) in the southern estuaries ; but in the Dongara crayfish it is certain that the escaping, mature crayfish bear a general relation to the fishery as a whole, in that their progeny serve to repopulate other areas. Consequently the growth of limited coastal crayfisheries such as that at Dongara should not be encouraged unduly.

The Geraldton area coastal fishery is of a different type. Here, there is not a high lodgment of larvae on the shore reefs. The region is to some extent blanketed from the westward by the Abrolhos Reefs, and there appears to be only a light lodgment over the area between the Abrolhos group and the mainland. The general order of size succession is reversed and there is some degree of banking up of large crayfish along the coastal reefs. The fishery yields about 100,000 lb. a year and appears to be in a satisfactory condition.

The fact that these very different types of fishery exist suggests that it may be necessary to apply different management regulations to each area in order to ensure the best return of flesh weight at each.

IV. INVESTIGATIONS IN WESTERN AUSTRALIAN WATERS

(*a*) *Exploration and Commercial Testing*

(i) *Jasus lalandii.*—This species occurs from Cape Naturaliste to the Esperance area, but little is known of its population density and distribution, seasonal and otherwise, in particular areas. It would not be surprising to find that, where the coast trends north-easterly to the head of the Great Australian Bight, some such tendency might occur as is noted in connection with the north-westerly trend of the South Australian Eyre's Peninsula coastline. In that area the population density appears to diminish north-westerly, while the shelf area occupied appears to be less and less, with a high degree of seasonal movement. The species tends to avoid waters of consistently higher temperatures (18° C. and upwards), particularly during moulting, mating, and "berry" periods. In the Western Australian waters a knowledge of the species' distribution at various depths, together with some indication of its seasonal movements, is required. Such exploratory work demands consistent and intensive investigations, and it is hoped that during the coming years the Division's research vessel, *Warreen*, now in commission after war service, may be able to make tests which will lay the foundation for commercial exploitation.

Since it has been found by the writer that onshore shallow water distribution of juvenile crayfish bears a close relation to the offshore distribution of adults (*J. lalandii* in South Australia, and *P. longipes* in Western Australia), coastal surveys of the south coast area, eastward of Point D'Entrecasteaux, could assist the sea work. One such survey has already demonstrated the presence of small *Jasus lalandii* westward of Albany and in the Cape D'Entrecasteaux area. Commercial tests are required using types of boats and gear economically suited to the general conditions, and conducted by skilled fishermen, operating in relation to the necessary storage, transport, and marketing requirements. Before this can be done a study of weather, sea, and shelter conditions is necessary. Indications are that at least limited fisheries could be established.

(ii) *Panulirus longipes.*—Since the dominant range of this species is now well known, little further exploratory testing is required. Commercial and biological testing of the grounds of the North-West Cape Peninsula is required. Exploratory work is required in the island reef areas of the coastal shelf north-easterly and northerly of North-West Cape.

(iii) *The "Coral" crayfishes.*—Little is known of the distribution of the three species involved. Exploration and commercial testing are required in the areas northerly from North-West Cape.

(*b*) *Technical Investigations*

(i) *Jasus lalandii*

The type of pot required in the southern waters for this species is being investigated. The type of spot-welded pot designed for *P. longipes* is being tried out by the *Warreen*, but, as already stated, its design is not suitable for capturing this species, and models in spot-welded wire, but following South Australian design, are in preparation.

(ii) *Panulirus longipes*

(1) *Rotproofing of pot ropes.*—Tests of the rotproofing compound, copper naphthenate, on the hauling ropes indicate that under fishery conditions the effective life of the rope is doubled as compared with that obtained by using bark tans.

(2) *Discolouration in canned crayfish.*—Cannery technique has been the subject of many tests during the past year, and these have resulted in a pearly white pack of fair quality. Among other things it has been found that pack quality and colour are best where the water loss during processing is least. The technique which ensures the least tissue water loss includes stunning the crayfish by immersion in freshwater, and immediately subjecting it to a brief cooking period, sufficient only to coagulate the flesh.

The findings of Fellers and Parks (1926) on the causes of the various types of discolouration in Pacific coast crabs appear to stand with slight modifications for *P. longipes.* The chief difference is that tissue colour changes, due to the formation of cupric-ammonia salts, permeate the whole of the tissue. Experiment has shown that the resultant tissue darkening is readily controllable for canning purposes by the addition of hydrated aluminium chloride, $AlCl_3.6H_2O$, to a slightly acid brining dip in the proportion of 200–400 p.p.m. by weight. Crayfish blood contains haemocyanin, an organic compound, as the chief oxygen fixing agent, and the copper from this and in storage in the tissues forms the tissue darkening compounds after death. Aluminium, which forms colourless compounds, readily replaces the copper in dilute, faintly acid solutions, and the practice is based on this fact. The procedure to ensure a good product should include the following steps ; a brief preliminary cooking period, treatment in the acid brining dip with a soluble aluminium salt, parchment lining of double laquered cans, topping off the filled can with weakly acid brine, the shortest retorting time consistent with effective sterilisation, and the rapid cooling of the retorted cans.

(3) *Frozen tails.*—Darkening of the stump of the tail owing to blood films coagulating on the outside of the flesh occurs with about one in every ten tails. The best procedure is to sort these and to wash them in a bath of a dilute acid solution of either aluminium chloride or aluminium sulphate as above. Freezing with the tail-fan downwards or with the tail on its side prevents free drainage of blood and reduces the likelihood of freezing discolouration. Slowness in freezing permits of a certain amount of drainage both into the dorsal sinus and externally as well as rupturing the tissues through the formation of large ice crystals, and is to be avoided. The use of bleaches such as chloride of lime is not good practice, since the blanched flesh becomes very tough during storage and thaws out in a very ragged condition, but treatment with a dilute (200–400 p.p.m.) solution of an aluminium salt, as above, is effective. For the best results it is essential that the crayfish be processed while it is still active, and the tail quickly prepared and rapidly frozen. It is essential that the lid be applied to the box with the minimum of pressure in order to avoid forcing liquid from the tails. A crystallisation time of about one hour is indicated. It must be emphasised that crayfish of the genus *Panulirus* are not as good subjects for freezing technique as are those of the genus *Jasus*, and the margin for error is much less.

(4) *Water Content of Muscle.*—Table 8 gives in detail the result of a test made on the water content of the major extensor muscle of the tail at the first and second abdominal segment of *P. longipes*, Rat Island, Abrolhos Group Catch, June 18, 1946. The method used was that of Dean and Sparks modified by Lowndes and Panikkar (1941). distillation of a known weight of tissue plus a small known volume of sea-water under xylol, using a Quickfit type of condenser. The number of determinations was small but the results suggest, as has been found for other Crustacea (Drach, 1939), that there is a relation between

tissue water and the intermoult phase and that a detailed investigation would be of value in cannery practice, as both cannery experience and water tests on cooked cray muscle show that the best cannery recovery rate is obtained from crayfish in the hard-shell state. In order to get the best results in both pack quality and recovery rate, modifications must be made in the treatment process from time to time, and the nature of these modifications depends on the moult condition of the crayfish which are being treated. The manner in which a crayfish tail reacts to processing and freezing also depends largely on its position with regard to the moulting cycle. The best results are obtained from mature crayfish well past the moulting period.

TABLE 8

WATER CONTENT OF ABDOMINAL MUSCLE

Weight of each sample 10·0 g. Volume of each sample 9·0 ml.

Intermoult	Colour	Sex	Length (in.)	Water (ml.)	Water (% of Vol.)	Water (% of W.)
Early post-moult ...	Pink	♂♀♂♀♂	$9\frac{3}{4}$	7·9	87·7	79
Post-moult	Pink		$8\frac{3}{4}$	7·3	81·1	73
Early mid-moult ...	Pink		10	7·2	80·0	72
Mid-moult	Red		10	6·9	76·6	69
Mid-moult	Red		10	6·85	76·1	68·5
Pre-moult	Dark Red ...		11	7·05	78·4	70·5

(5) *Copper in crayfish blood.*—Mr. A. B. Beck, an officer of the Division of Animal Nutrition, C.S.I.R., is conducting tests of the amount of copper present in a unit volume of the blood of specimens of *P. longipes*. The copper values ranged from 43 to 208 micrograms per millilitre over the 38 specimens which have been tested up to the present (each crayfish was tested once only). There was no indication, in these specimens, that the variation was related to the crayfish size, the month of the year, the fishing grounds where the crayfish had been captured, the length of time it had been out of the water, its state of reproductive activity, or to the time which had elapsed since the crayfish had moulted. The detailed results will be published elsewhere.

(c) *Biological Investigations*

(i) *Jasus lalandii.*—The Division of Fisheries, C.S.I.R., is co-operating with the Department of Biology, University of Tasmania (Professor V. V. Hickman), on various aspects of the biology of this species, so that in Western Australia the chief emphasis will be on the biology of *P. longipes*.

In South Australian waters, using containers in wells of boats constantly in open neritic waters, the author has reared larvae of *J. lalandii* through five moults. The mortality was exceedingly high and three only of 400 larvae carried into the fifth moult. The period covered two months. It was not possible to keep tow-netted specimens of the fifth or sixth moults, from the edge of the continental shelf waters, alive for any length of time ; but specimens of the fourth or fifth moult, from shelf waters, lived until the beginning of the next moult. Since the rate of growth and number of moults within a given period

in crustacean larvae apparently depend on temperature and on nutrient intake, and to a lesser extent upon degree of organisation, the relation of the two months required for passing to the fifth stage under more or less artificial conditions to the time taken under natural conditions is not known.

(ii) *Panulirus longipes.*—From the point of view of fishery management and rational exploitation detailed information is required in each sub-area, on the following : (i) mating seasons, (ii) spawning period, (iii) duration of larval life, (iv) bearing of current and surface wind-drift systems on the distribution of larvae, (v) depth distribution of the various size groups of the crayfish form, (vi) age to maturity and growth rates, (vii) periods of the year over which the main male and female moults take place, (viii) environmental preferences of juveniles and adults, (ix) time elapsing between successive spawnings of a female, (x) population densities in areas commercially fishable and in adjacent areas commercially unfishable, (xi) movements of adult crayfish during the season, (xii) sources of recruitment of the stocks on fishery areas, (xiii) measurements of the weight of flesh actually obtainable from crayfish of different sizes.

Considering the temperature differences over the range of the species it should not be expected that answers to these questions in one area, such as the Abrolhos, would necessarily apply to another area such as Rottnest Island.

In the relevant sections of these notes a general outline of the biology of *P. longipes* covering some of the problems listed above has been given. However, it has not been possible to study the species in very great detail. Age to maturity, age groupings, and intermoult durations are not very well known owing to the high size variability of the crayfish and the fact that growth in an individual cannot be measured as continuous increments of weight or length. It would appear at first sight that all that would be necessary would be to measure the growth and development of specimens in captivity. This would give information only in the terms of the experiment. What is required is information in terms of field conditions so that the attributes of the crayfish entering the fishery from various sources and at different places can be determined. In fish groups useful checks on the results obtained by the analysis of length or weight frequencies have been developed through studies of growth in scales and in sections of otoliths. As growth in the Crustacea is possible only through the shedding of the exoskeleton, with the consequent periodical loss of all external fixed marks, no such check on length or weight frequencies has appeared possible. However, an examination of a large number of specimens of *P. longipes* over the past twelve months has indicated that a relation may exist between the number of rows of denticles in the telson, the number of canals in the telson, and the carapace length, and that this relation may assist in obtaining true age groupings.

The work carried out during 1947 included a series of tagging and punchmarking tests on about 10,000 crayfish in the Abrolhos region, together with a continuous fishing test in a restricted area. The tests were designed to give information on the following :

(i) The direction and rate of movement of the crayfish over the Abrolhos grounds in order, among other things, to gain a measure of the rate of replenishment of the fishery grounds.

(ii) The estimation of the population existing at a given time at various grounds and of the rate and nature of the replacement of the population under fishery conditions.

(iii) The estimation of the duration of the intermoult period at different sizes, and of growth increments over the season.

(iv) The estimation of the various age groups which are the subject of the fishery.

Other work included a monthly market sampling of the carapace lengths of the Abrolhos commercial catch, a continuous fishing test in a limited area at Southern Group and an examination of the " white " crayfish of the Rottnest Island area. Market samplings of the Abrolhos commercial catch are being continued during 1948, while a continuous catching test in the charge of Mr. R. Page of Geraldton is being carried out in order to test the rate of intake of crayfish from deep waters west of the Abrolhos shallow-water fishing areas.

TABLE 9

PANULIRUS LONGIPES (HOUTMAN'S ABROLHOS).
Marking Summary April–July, 1947
Recaptures—1947.

	Oval	Circle	Heart	Diamond	Total
(*a*) *Release and Recapture Tests*					
Males marked	648	1,406	1,222	...	3,276
Males recaptured	60	206	105	...	371
Females marked	274	690	696	...	1,660
Females recaptured	39	57	78	...	174
Total marked	922	2,096	1,918	...	4,936
Total recaptured	98	263	183	...	544
Total catch	1,020	2,359	2,101	...	5,480
(*b*) *Release Tests*					
Males marked	644	738	156	1,779	3,321
Females marked	188	281	35	1,952	2,456
Total marked	832	1,019	191	3,731	5,777
Recaptured	106	132	21	...	238
(*c*) *Summary*					
Males marked	1,292	2,144	1,378	1,779	6,593
Females marked	462	971	731	1,952	4,116
Total marked	1,754	3,115	2,109	3,731	10,709
Total recaptured	204	395	204	...	782
Per cent. recaptured	11·6	12	9·6	...	11·2

The marking tests during 1947 were carried out from the fishing boat *Maori Lass*, chartered by the Division of Fisheries, and were divided in two parts. Firstly, crayfish were marked and released at random within the measured area of capture in order that the numbers recaptured during the marking tests could be used as measures in estimating population numbers. Since the tests were carried out at relatively isolated grounds at a time when there was little evidence of crayfish movement, a formula derived by Schnabel for the determination of the fish population of lakes was used. The formula is $P = \frac{S(AB)}{S(C)}$, (Ricker 1945, p. 78), where P = population to be estimated, A = catch on one day, B = marked crayfish at large in the area on that day, C = marked crayfish in the day's catch, "S" signified that the quantities within the brackets are to worked out for each day's catch and then totalled ; the division of the totals is then made.

The population limits given in Section III. (*f*) Conservation, were estimated by this method from the daily catch during the tests in each area. They were checked by comparing the recaptures and releases with the commercial catch over the period, by analysing the results of the continuous fishing test, and by considering the rate at which the modal size class was reduced during the commercial fishing operations. The results from each of these methods fell within the limits given in the section.

In the second part of the experiment the crayfish were released in order to obtain some idea of their subsequent movements. Recaptures were made by the fishermen in the course of their operations during the season. The results are given in Figure 1; the lines radiating from the marking centres represent the least path of the crayfish from point of release to the point of recapture. The solid lines represent recoveries made during 1947, the broken lines those made during the early part of 1948.

No recoveries of the crayfish marked with a diamond were expected in the commercial catch during 1947. These crayfish were all immature and under the legal minimum size ($2\frac{3}{4}$ in.) and were released at Rat Island in an area which was not fished. Two of these crayfish were caught at the Eastern Island, Easter Group, during April, 1948. They were mature and their respective carapace lengths were 3.5 in. and 3.8 in., an increase of length in nine months of at least 0.7 in. and 1.1 in. A summary of the marking operations is given in Table 9.

V. A WORKING KEY TO THE GENUS *PANULIRUS*

(A) Abdominal tergites, grooves present. Exopod of third maxilliped present.

(B) Abdominal tergites, grooves not interrupted.

(C) Third maxilliped, exopod present.

(D) Third maxilliped flagellum present, multiarticulate.

(E) Antennal segment, two principal spines, anterior to these 3–5 small spines, posterior smooth ; abdomen punctuate ; third maxilliped, flagellum reaches to middle of 4th segment (merus). .... *P. japonicus* (von Siebold)

(EE) Antennal segment, two principal spines, anterior to these 4–6 tubercles, posterior 4–6 spines ; abdomen smooth ; (maxilliped ; flagellum as in *P. japonicus*).....*P. longipes** (Milne-Edwards)

(DD) Third maxilliped, flagellum, uniarticulate or absent (second maxilliped with flagellum).

(F) Antennular segment, two principal spines.
.....*P. guttatus* (Latreille)

(FF) Antennular segment, four principal spines.
.....*P. penicillatus** (Olivier)
(Each posterior spine is joined to its corresponding anterior spine at the base.)

(CC) Third maxilliped, exopod absent.....*P. burgeri** (de Haan) (second maxilliped, flagellum, uniarticulate or absent, abdominal grooves with the anterior margin scalloped)

(BB) Abdominal grooves interrupted in midline.

(G) Third maxilliped, exopod present, flagellum present.

(H) Epistome, the three teeth equally developed. Epimeres, posteriorly denticulate.
.....*P. interruptus* (Randall)

(HH) Epistome, medium tooth the largest. Epimeres posteriorly smooth.
.....*P. argus* (Latreille)

(GG) Third maxilliped, exopod absent.

(I) Second maxilliped, exopod with multiarticulate flagellum ; abdominal grooves not dentate.....*P. regius* (De Brito Capello)

(II) Second maxilliped, exopod with rudimentary single segmented flagellum ; abdominal grooves on second and third segments only, shallow, pilose not dentate.....*P. versicolor** (Latreille) (young specimens only)

(III) Second maxilliped, exopod with no flagellum ; abdominal grooves dentate.....*P. dasypus* (Latreille)

(AA) Abdominal tergites, grooves absent. (Third maxilliped, exopod absent or present as a rudimentary button only)

(J) Second maxilliped, exopod with multiarticulate flagellum.

(K) Antennular segment with two principal spines.....
.....*P. polyphagus* (Herbert) [(= *P. fasciatus* (Fabricius)]

(KK) Antennular segment with four principal spines.

(L) Colour reddish-green, yellowish stripes on first three abdominal segments and on legs.
....*P. inflatus* (Bouvier)

(LL) Colour reddish-green, yellowish spots on abdomen and legs.
.....*P. laevicauda* (Latreille)

(JJ) Second maxilliped, exopod with flagellum uniarticular or absent.

(M) Second maxilliped, exopod, flagellum uniarticular (abdomen with whitish bands).....*P. versicolor** (Latreille) (old specimens)

(MM) Second maxilliped, exopod with flagellum absent (abdomen generally with yellowish patches).....*P. ornatus** (Fabricius)

* Species recorded from Australian waters.

This key gives selected morphological characteristics for each of the recognised species. It is fairly certain, however, that some of the species, *e.g.*, *P. japonicus* and *P. ornatus*, are complex. Colour patterns have not been included in this key (with the exception of *P. inflatus* and *P. laevicauda* for which no other criteria are available). In general in this genus colouration is very variable. However, colour pattern is in a sense stable, in that if a species is characterised by stripes on the legs or other parts, some stripes are always present whether as paler than the ground colour or as a yellow, cream, or white—this is also true of spot patterns. For instance, faint, white, or parchment-yellow stripes are always present on the legs of *P. longipes* which also possesses white or parchment yellow oval or crescent markings on the abdominal terga ; *P. versicolor* is characterized by light bands outlining the abdominal segments, bars of white or yellow across the pleopods, the main carapace spines, and antennae ; while with *P. burgeri* the light, olive or dark green ground colour is relieved by numerous white or pale yellow dots.

VI. ACKNOWLEDGMENTS

During 1946 it was possible, with the assistance of the Western Australian Chief Inspector of Fisheries, Mr. A. J. Fraser, and his inspectors, particularly Messrs. H. J. Murray, J. Traynor, S. W. Bowler and H. C. W. Piesse of Geraldton and Messrs. X. W. Stathy and A. J. Bateman of Fremantle, to collect this data for a preliminary investigation of the crayfishery of Western Australia. The co-operation of the fishermen was wholehearted, in particular during the marking and continuous fishing tests, that of Messrs. J. Baseden and R. Page of the *Maori Lass*, while Messrs. V. Basile senior, Victor Basile junior, Vincent Basile and S. Merendino of the *Tartan*, V. and F. Camarda and C. Glorioso of the *Hood*, provided necessary transport, hospitality, and assistance in the Abrolhos area. Members of the Royal Australian Navy co-operated in distribution tests. The manager, Mr. L. Devlin, and the secretary, Mr. E. L. Wilson, of Geraldton Canneries, Ltd., provided facilities at Geraldton, Mr. A. O. Gaze of Pelsart Island extended hospitality and assistance, while Messrs. C. Garratt and R. Carlberg of Geraldton gave unrestricted access to their books and records.

Officers of several Divisions of C.S.I.R. in Western Australia, members of the staffs of the Departments of Biology and Geology, and students of the University of Western Australia and officers of the State Department of Agriculture, gave voluntary assistance during many of the long field trips. The University of Western Australia made laboratory space available at the Institute of Agriculture and later at the Department of Biology. Mr. S. Fowler, Division of Fisheries, C.S.I.R., supplied field notes made during his aerial surveys ; Mrs. Sheard gave considerable field and clerical assistance. Thanks are also due to the following officers of the Division of Fisheries, Mr. G. W. Rayner, Dr. D. L. Serventy, Dr. A. G. Nicholls, and Mrs. L. M. Willings, for reading and criticising the manuscript.

VII. REFERENCES*

Bate, C. S. (1888).—Crustacea Macrura. *Challenger Mem.* 24 : 77–9.

Beck, A. B., and Sheard, K. (1949).—The copper and nickel content of the blood of the Western Australian marine crayfish, *Panulirus longipes*, (M.-E.), *Aust. J. Exp. Biol. Med. Sci.* (in press).

Bumpers, H. C. (1901).—On the movements of certain lobsters liberated at Woods Hole during the summer of 1898. *Bull. U.S. Fish. Comm.* 19 : 33.

Chaisson, A. F. (1932).—Factors in the shipment of live lobsters from eastern Nova Scotia. *Bull. Biol. Bd. Can.*, 32 : 1–29.

Crawford, D. R. and De Smidt, W. I. J. (1922).—The Spiny Lobster, *Panulirus argus*, of Southern Florida. Its natural history and utilisation. *Bull. U.S. Bur. Fish.*, 37, 1921–1922. Doc. No. 925 : 281–310.

Dakin, W. J. (1915).—Marine biology in Western Australia. *J. Roy. Soc. W. Aust.*, 1 : 11–27.

Dakin, W. J. (1919).—The Percy Sladen Trust Expedition to the Abrolhos Islands (Indian Ocean). *J. Linn. Soc. (Zool.)*, 34 : 127–87.

Drach, P. (1939).—Mue et cycle d'intermue chez les crustaces decapodes. *Ann. Inst. Océanogr. Monaco*, 19 (3) : 103–391.

†Elmhirst, R. (1923).—On the moulting of the lobster. *Proc. R. Phys. Soc. Lond.*, 20 : 271.

Fairbridge, R. W. (1948).—Notes on the geomorphology of the Pelsart Group of the Abrolhos Islands. *J. Roy. Soc. W. Aust.*, 30 : 1–44.

Fellers, C. R. and Parks, G. T. (1926).—Biological study and proximate composition of Pacific Coast crabs. *Univ. Wash. Publ. Fish.*, 1 (7) : 139–56.

Gruvel, A. (1911).—Contributions a l'étude general systematique et economique des Palinuridae. *Ann. Inst. Océanogr. Monaco*, 3 (4) : 1–51.

Herrick, F. H. (1895).—The American Lobster. *Bull. U.S. Fish. Comm.*, 5 : 1–252.

Hickman, V. V. (1946).—Notes on the Tasmanian marine crayfish, *Jasus lalandii* (Milne-Edwards). *Pap. Proc. Roy. Soc. Tas.*, 1945 : 27–38.

Kinosita, T. (1933).—On the propagation of the Spiny Lobster, *Panulirus japonicus* (von Siebold). *Bull. Jap. Soc. Sci. Fish.*, 1 (5) : 113.

†Kinosita, T. (1934).—On the artificial propagation of *P. japonicus* and some account of its larvae. *Proc. 5th Pan-Pacif. Sci. Cong.* (Univ. Press : Toronto.)

Kubo, I. (1938).—Notes on the sexual dimorphism of the Spiny Lobster, *Panulirus japonicus* (von Siebold). *J. Fish. Inst. Tokyo*, 33 (1) : 101–6.

Lowndes, A. G. and Panikkar, N. K. (1941).—A note on the changes in water content of the Lobster (*Homarus vulgaris*) during moult. *J. Mar. Biol. Ass. U.K.*, 25 : 111–2.

MAN, J. G. DE (1916).—The families Eryonidae, Palinuridae, Scyllaridae, and Nephropsidae. *Siboga Exped. Monogr.*, 29a (2): 1–122.

NAKAMURA, S. (1940).—Ecological studies on the Spiny Lobster, *Panulirus japonicus*, with special reference to its conservation. *J. Fish. Inst. Tokyo*, 34 (1): 101–3.

PEARL, R. and CLAWSON, A. B. (1907).—Variation and correlation in the crayfish. *Carnegie Inst. Publ. Washington*, 64: 1–70.

RATHBUN, M. J. (1906).—The Brachyura and Macrura of the Hawaiian Islands. *Bull. U.S. Fish. Comm.* 23 (3): 827–930.

RICKER, W. A. (1945).—Some applications of statistical methods to fishery problems. *Biometric. Bull.*, 1 (6): 73–9.

SMITH, G. F. M. (1939).—The effect of size limit on commercial lobster catches. *Prog. Rep. Atlant. Biol. Sta.*, No. 25: 10.

SMITH, G. F. M., and MARSHALL, N. (1945).—Preliminary report on the Florida crawfish investigation. *Univ. Miami, U.S. Mar. Lab.* (Roneo copy): 1–28.

TEICHERT, C. (1947).—Contributions to the geology of Houtman's Abrolhos, Western Australia. *Proc. Linn. Soc. N.S.W.*, 71: 145–96.

TEMPLEMAN, W. (1935).—Lobster tagging in the Gulf of St. Lawrence. *J. Biol. Bd. Can.*, 1 (4): 269–78.

TEMPLEMAN, W. (1939).—Investigations into the life history of the lobster on the west coast of Newfoundland, 1938. Dep. Nat. Resources, Newfoundland. Res. Bull. Fisheries No. 7: 1–52.

TEMPLEMAN, W. (1940).—Lobster tagging on the west coast of Newfoundland, 1938. Dep. Nat. Resources, Newfoundland. *Ibid.* No. 8: 1–16.

THOMPSON, H. (1934).—Newfoundland Lobster Industry. Interdep. memo. from Director Fish. Res. Lab. to Commissioner of Dep. Nat. Resources, Newfoundland: 1–23.

VON BONDE, C. (1935).—Studies in canning of Cape crawfish. Fish and Mar. Biol. Surv. S. Afr. Invest. Rep. No. 5: 1–16.

VON BONDE, C. (1936).—The reproduction, embryology and metamorphosis of the Cape crawfish (*Jasus lalandii*). *Ibid.* Invest. Rep. No. 6: 1–25.

VON BONDE, C., and MARCHAND, J. M. (1935).—The natural history and utilisation of the Cape crawfish, reef or spiny lobster (*Jasus lalandii*). *Ibid.* Fish. Bull. No. 1: 1–40.

WILSON, R. C. (1948).—A review of the Southern California spiny lobster fishery. *Calif. Fish Game* 34 (2): 71–80.

* This list of references is published as a basic working list in addition to serving as an index of the references in the text.

† Paper seen in abstract only.

By Authority: WILLIAM H. WYATT, Government Printer, Perth.

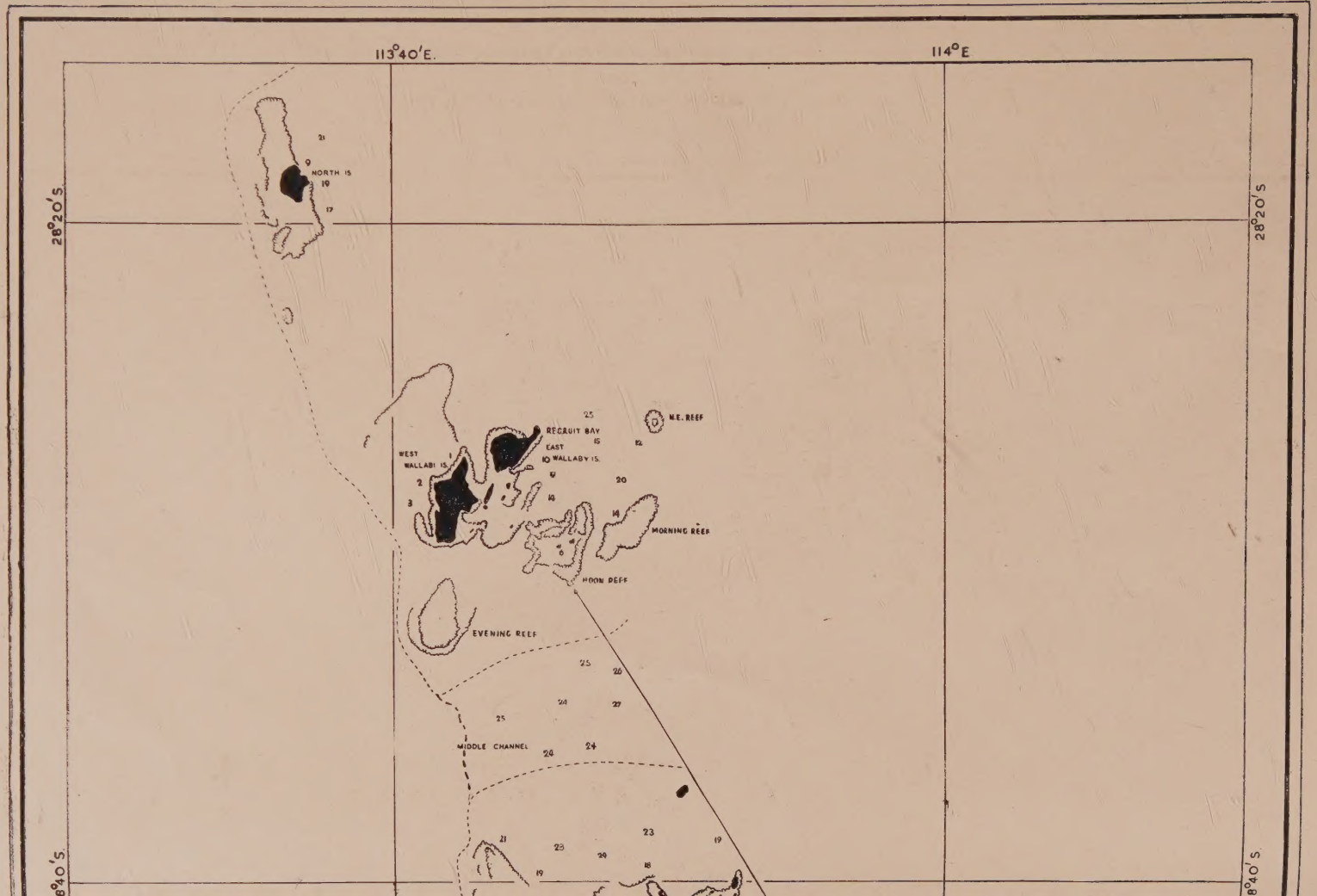
113°40'E.
114°E
28°20'S
28°40'S
NORTH IS
WEST WALLABI IS.
EAST WALLABY IS.
RECRUIT BAY
N.E. REEF
MORNING REEF
NOON REEF
EVENING REEF
MIDDLE CHANNEL

Figure 1.

Movements of marked crayfish. Houtman's Abrolhos, Western Australia.

————————, 1947; - - - - - - - - - - - -, 1948.

Chart compiled from Admiralty charts and data of R. W. Fairbridge and K. Sheard.

RECENT BULLETINS

201. Grazing Management: Continuous and Rotational Grazing by Merino Sheep
202. The Strain Complex and Symptom Variability of Tomato Spotted Wilt Virus
203. Agar in Australia
204. A Soil Survey of Part of Waterhouse Estate, County of Dorset, North-East Coast, Tasmania
205. Studies on the Breeding Performance of Ewes
206. Pedogenesis following the Dissection of Lateritic Regions in Southern Australia
207. The Fumigation of Wheat in Bag Stacks
208. Surface Fumigation of Insect Infestations in Bulk-Wheat Depots
209. Interaction of Insect Infestation, Temperature, and Moisture Content in Bulk-Depot Wheat
210. Preliminary Survey of the Natural Pastures of the New England District of New South Wales and a General Discussion of Their Problems
211. The Water Retting of Flax
212. The Frictional Properties of Lead-base and Tin-base Bearing Alloys
213. Laboratory and Field Tests of Mosquito Repellents
214. The Preparation and Properties of Synthetic Cryolite
215. Studies in the Biology of the Skin and Fleece of Sheep. Part 4
216. An Examination of the Peet-Grady Method for the Evaluation of Household Fly Sprays
217. The Relative Importance of Live Sheep and of Carrion as Breeding Grounds for the Australian Sheep Blowfly (*Lucilia cuprina*)
218. Studies of the Physiology and Toxicology of Blowflies. Parts 12 and 13
219. Spray Tests against Adult Mosquitoes. Parts 1 and 2
220. The Preparation and Use of Harvey's Reduced Strychnine Reagent in Oceanographical Chemistry
221. Contributions to the Study of the Cell Wall. Parts 4 and 5
222. The Chaetognatha of South-eastern Australia
223. Report of Marine Borer Survey in New Guinea Waters
224. Mechanical Composition of Soil in Relation to Field Descriptions of Texture
225. Studies on the Control of Wheat Insects by Dusts
226. An Ecological Study of the Australian Plague Locust (*Chortoicetes terminifera* Walk.) in the Bogan-Macquarie Outbreak Area, New South Wales
227. Studies on Perennial Veldt Grass (*Ehrharta calycina* Sm.)
228. Ecological Observations on the Small Plague Grasshopper, *Austroicetes cruciata* (Sauss.), in the Trangie District, Central Western New South Wales
229. Studies in Cement-Aggregate Reaction
230. The Preparation and Properties of Aluminium Fluoride
231. Mint Weed (*Salvia reflexa* Hornem.) Present Distribution and Status in Australia
232. Guide to the Medicinal and Poisonous Plants of Queensland
233. A Soil Survey of the Hundred of Seddon and part of the Hundred of MacGillivray, Kangaroo Island, South Australia
234. Mineral Deficiency in Plants on the Soils of the Ninety-mile Plain in South Australia. Part 2
235. The Algal Genus (*Gracilaria*) in Australia
236. Observations on the Plant Communities at "Bundemar," Trangie District, New South Wales, in relation to *Chortoicetes terminifera* (Walk.) and *Austroicetes cruciata* (Sauss.)
237. Heating in Stored Wheat. Parts 1, 2, and 3
238. The Non-parasitic Disorders of Apple Fruits in Australia
239. Foundry Sand Resources of New South Wales
240. Studies on Dietary and Other Factors Affecting the Serum-Calcium Levels of Sheep
241. An Australian Phytochemical Survey. I. Alkaloids and Cyanogenetic Compounds in Queensland Plants
242. The Age, Rate of Growth, and General Life-history of the Australian Pilchard (*Sardinops neopilchardus*) in New South Wales Waters
243. A Soil, Land-Use, and Erosion Survey of Parts of the Countries of Moira and Delatite, Victoria, including the Parishes of Pine Lodge, Dookie, Devenish, Currawa, Stewarton, Caniambo, Gowangardie, Upotipotpon, Goomalibee, Tamleugh, Shadforth, Wills, Warrenbayne, Boho, Moglonemby, and Balmattum
244. Observations on Wheat in a Victorian Bulk Depot
245. Observations on the Behaviour of Swarm Hoppers of the Australian Plague Locust *Chortoicetes terminifera* (Walker)
246. Plankton Characteristics, Cronulla Onshore Station, New South Wales, 1943–1946